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ERGONOMICS

HUMAN FACTORS IN WORK, MACHINE CONTROL AND EQUIPMENT DESIGN

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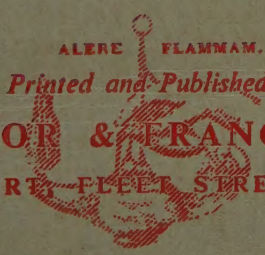

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ERGONOMICS

Human Factors in Work, Machine Control and Equipment Design

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Immediate and Low Level Effects of Ionizing Radiations

Edited by A. A. Buzzati-Traverso

Proceedings of The Symposium held at Venice in June 1959 under the joint sponsorship of U.N.E.S.C.O., I.A.E.A. and C.N.R.N. and published as a supplement to the International Journal of Radiation Biology

The effects of low level radiation, from a biological point of view, have received relatively little attention during many meetings on radiobiology held in the past years. The subject, however, appears of primary significance at this time, in view of the widespread use of radiation sources for scientific, medical, industrial and military purposes. For this reason a symposium exclusively devoted to the subject was called for. Thanks to the financial support of U.N.E.S.C.O., I.A.E.A. and the Italian Atomic Energy Agency (C.N.R.N.) and the hospitality of the Fondazione Giorgio Cini, Z. M. Bacq (Belgium), E. Boeri (Italy), A. A. Buzzati-Traverso (Italy) and A. Hollaender (U.S.A.) organized an international symposium on " The Immediate and Low Level Effects of Ionizing Radiations " which has been held at Venice in June 1959. The meeting was attended by some 120 specialists from many countries.

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EXPERIMENTAL PSYCHOLOGY IN THE FIELD OF TELECOMMUNICATIONS

By R. Conrad

Medical Research Council's Applied Psychology Research Unit, Cambridge

Four examples are cited to illustrate the application of the methods and principles of experimental psychology to practical telecommunications problems.

(1) The decay theory of immediate memory was used to predict the relative merits, in terms of error, of the telephone dial and an alternative of a set of 10 push buttons. Predictions were also made regarding the effect of a prefix digit on accuracy of recall. Experiments substantially confirmed the predictions.

(2) Laboratory experiments were used to investigate factors relevant to the design of long telephone codes for easy remembering. Factors considered were : Length ; grouping ; letters *v.* numbers.

(3) An operational telephone exchange was used for 5 weeks during a controlled experiment on the effects on operators' performance of varying the traffic load. Operator time per call was shown to be a function of traffic per operator.

(4) The frequency distribution of the time to sort letters by key pressing was recorded in the practical situation. The effect of practice is shown, and the influence of a machine lag in restraining output is demonstrated.

§ 1. Introduction

Although ergonomics is an established scientific discipline, there are very few ergonomists. Contributions to ergonomics research come therefore from a variety of sources, one of which is experimental psychology. The psychologist in this context is usually concerned with applying theoretical concepts to practical problems of work. But he is not averse to using those working situations to confirm and expand his theoretical knowledge. The present paper cites four case-histories which illustrate this process.

§ 2. Instrument Design

The decay theory of immediate memory was developed in the earliest days of experimental psychology. No one then imagined that it could have any relevance to telecommunications, in the modern sense of that word. It was argued that seeing or hearing something to be remembered set up some kind of a trace in the mind, which decayed naturally with time—hence forgetting. Few persons today would insist on the exclusiveness of this theory to account for all forgetting, but at the same time there is a good deal of evidence to suggest that some forgetting is due to decay of a not very clearly defined trace of something. As we now know, in effect this means that images perceived or events experienced fade fairly quickly, unless traces initially established are continually strengthened.

Clearly decay theory seems relevant to the problem of remembering a series of digits—say eight or nine—for long enough to dial them by telephone. This is a problem that is becoming increasingly common all over the world as telephone networks grow. The reason why decay theory is interesting in this context is because the telephone dial forces on the person dialling a series of delays between digits—of an average duration of nearly a second. If one

wants to use these intervals to rehearse mentally the remainder of the number, one finds that they are just about of borderline value for this purpose. One might be able to use the delay after the nine or zero, but probably not that after one, two or three. So that, according to the theory, during these short delays while waiting for the dial to return, the memory trace established on first reading the number, is now decaying, thus increasing the chances of dialling the wrong number (Conrad and Hille 1958 a).

One might think that the solution would be to use a system which minimized inter-digital delays such as, for instance, a set of ten push buttons. It has been possible to test this prediction experimentally, using subjects who were equally experienced at both dialling and keying telephone numbers (Conrad 1958).

Four experimental conditions were set up, randomized in Latin Squares, and each operator took part in all four. These were : dialling or keying 8-digit numbers, and dialling or keying 8-digit numbers but always prefixed by the digit 0. This prefix condition simulated the situation in the national trunk dialling system where the digit 0 precedes all trunk numbers and acts as a switch into the trunk network out of the local one. This too, according to decay theory ought to have led to more recall errors. The results are shown in the table.

Effect on recall of transmitting procedure

Procedure	Correctly transmitted (per cent)
Keying	56·9
Dialling	50·6
Keying with prefix digit	45·2
Dialling with prefix digit	34·8

§ 3. Dialling Codes

The new national trunk dialling system has just been referred to in connection with dialling codes. But these codes must first be designed so that a whole nation of people can successfully use them. As an example of the problem which already exists consider the code required to call the meteorological station at Mildenhall from a Cambridge telephone ; one dials the following sequence : 96618312274. The initial 9 is remembered as the standard prefix, and the 661831 comes from one directory, the remainder from a second directory. The temptation therefore to try to remember all or part of the number is strong—even for someone well aware of the fragility of immediate memory.

What would help this kind of situation ? For brevity three features may be considered. First of all from a psychological point of view, long numbers ought to be short ! It is not always realized how few digits or letters can be immediately recalled after hearing or seeing them once. Tests both on naval ratings and on female telephonists, groups which one would expect to be a little better than the average of the country as a whole, show that under ideal conditions an 8-digit number is correctly recalled about six times out of ten.

For 100 per cent correct recalls, it is useless with these groups to use numbers longer than five digits. If subjects are distracted for a few seconds between hearing and repeating back a number, then one could not expect 100 per cent success even with a 3-digit number.

The second feature is grouping. The optimum size of group proves to be three or four digits (Conrad and Hille 1957). Too much breakdown is in fact worse than none at all—possibly because when no grouping is suggested in the presentation, subjects create their own.

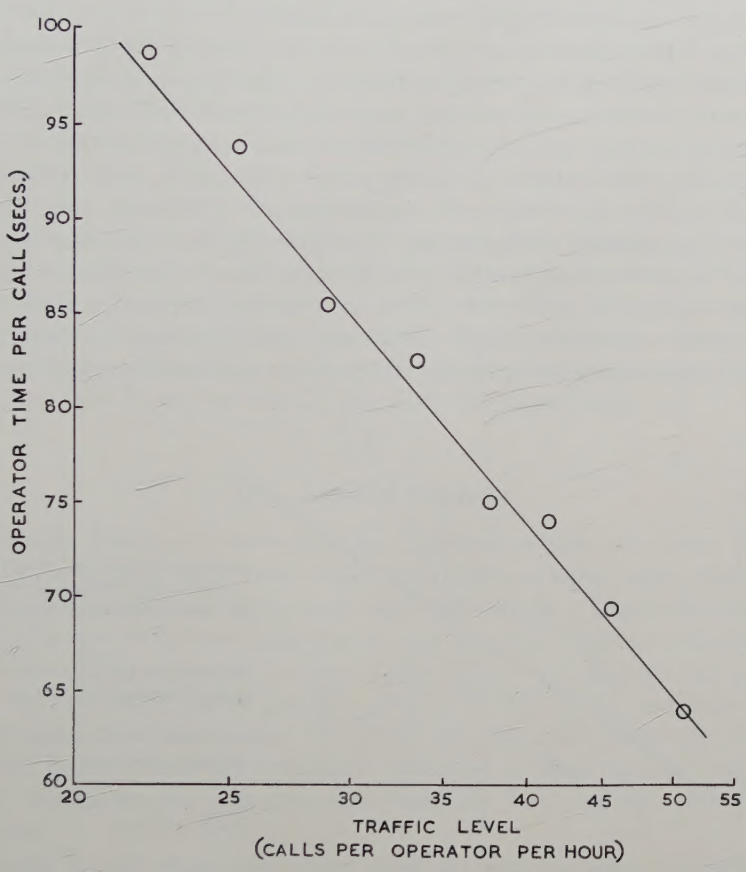

Figure 1. Effect on operator performance of telephone traffic level.

Thirdly there is the question of the relative value of digits and letters, and results here are also fairly clear. Letters which appear to be logical in the context, which can be deduced by simple rules, like the first three letters of London telephone exchanges, are always better than the same number of digits But letters which appear to be drawn at random from the alphabet are much more difficult to remember than digits. All-numeral codes are better than letter-number or number-letter codes. But if random letters have to be used, then they should occur as a group at the beginning rather than at the end. This is because the second half of a sequence of six characters is generally more difficult to remember than the first half (Conrad and Hille 1957).

§ 4. Staffing a Telephone Exchange

The third example of the use of techniques of experimental psychology in the communications field is drawn from a study made at a telephone exchange. In essence, the problem was to determine the number of operators required to handle the traffic. Correct staffing can be fairly critical. If there is too little traffic per operator, then operators are idle for much of the day. Too much traffic on the other hand will increase subscribers' waiting time in a logarithmic manner, so that, beyond a certain point, this waiting time soars fairly quickly, not only above what is regarded as good service but up to a point at which customers begin to abandon calls.

The Post Office have always dealt with this matter by a modified work study procedure which has enabled them to take into account the different kinds of traffic occurring in varying amounts at each exchange. But underlying the basis of the procedure is the fundamental assumption that the average time required by an operator to set up a call is constant, and independent of the rate at which calls come into the exchange. For some time though in laboratory experiments, evidence had been growing that this assumption was false ; that operator time to deal with an item, was a function of the rate at which items had to be dealt with. But since all the laboratory work has been concerned with relatively simple responses, and this was an item of work which might take one or two minutes, the problem was examined experimentally.

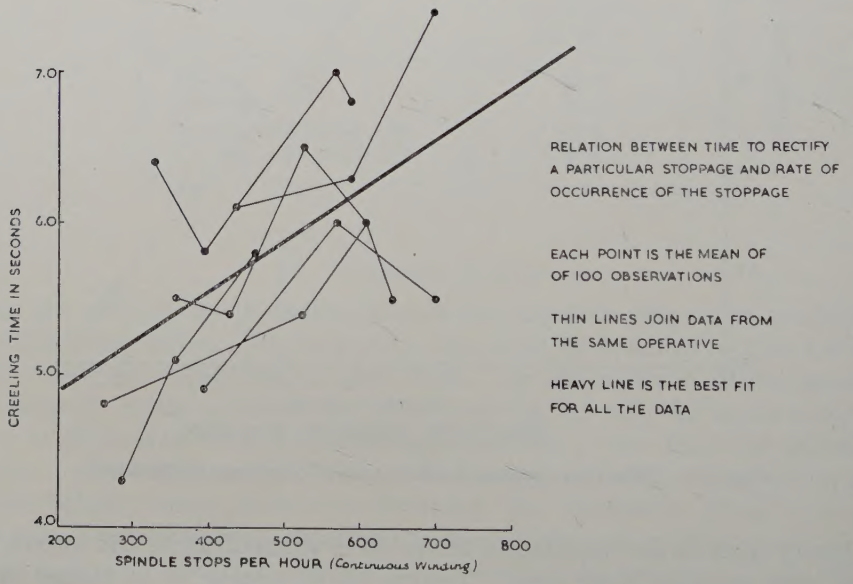

Figure 2. Effect of work-load on performance of textile operatives.

Essentially what was necessary was to vary in a systematic manner the amount of telephone traffic entering the exchange. But since one cannot stop subscribers from dialling O, the number of operators available to deal with the traffic was varied. With the help of some records from the previous year, an estimate was made of the number of calls expected hour by hour for the duration of the experiment which was to be five weeks. On this basis the size

of staff was varied, also hour by hour so that there was a more or less balanced experimental design which introduced a number of work-loads in a random order (Conrad and Hille 1958 b). The snap-reading method of Tippett (1935) was used to measure the time taken by operators to deal with a call. This gave the average operator time per call for the various traffic loads, a breakdown of the way in which she spent that time, and a measure of the time when she had no work available at all. The results are shown in Fig. 1 and it was clear that a substantial decrease in staff could be tolerated, without infringing G.P.O. standard of service.

To check on the possibility of experimental euphoria, Union agreement was obtained to staff the exchange for the whole of the summer of the following year on the basis of the results of the experiment. The experimental results were confirmed and those schedules have continued ever since.

It would be dangerous to dismiss this study merely as yet another example of Parkinson's Law. Fig. 2 shows the result of an experiment in a textile mill (Conrad 1951). In this case, increasing the amount of work *increased* the operator time per item. There is this one general point which may be emerging. If the work is coming in as a single stream, so that only one item at a time need be considered—the case of telephone operators—then increasing the rate of work, may *decrease* operating time per item. But if each item of work involves a choice between alternatives—the textile case—then an increase in the rate of work may lead to an *increase* in the time taken per item.

§ 5. Letter Sorting

The Single Position Letter Sorting Machine which the Post Office has recently brought into use in field trials, displays envelopes to an operator who, by means of a keyboard, sorts them into 144 boxes. The operation is self-paced ; i.e. a new envelope is displayed only when the operator dispatches the previous one. This arrangement inevitably leads to higher sorting rates than would a rhythmically paced system (Conrad 1955). The machine however cannot sort at a rate faster than 110 letters per minute. Although this rate is a good deal higher than the operators' expected average sorting rate, studies are being made to see whether this machine limit affects the operator's performance.

The times to sort each individual letter are automatically recorded in the form of a distribution table. The recording equipment allows for eleven different sizes of time interval. Recording began at a very early stage of practice—but after operators had had training on a simulator—and continued for many months during which there was continued improvement in sorting rate.

Figure 3 shows the performance of three operators. The top set of histograms represents early days in practice—the bottom set the more recent picture. A little care is needed in interpreting these pictures, because an unequal interval scale was used. The first column includes only times between the machine limit of 0·55 sec and 0·6 sec ; there are then steps of a fifth of a second, opening out to half seconds towards the end, and the last column contains all times longer than 3 seconds.

Even before these operators were fully practised it was obvious that there was something peculiar about these later distributions. Enough is known about the distribution of human response time to know that there are far too many times heaped up at the short end. Operators quickly learn that it doesn't pay to try to sort faster than the machine will permit, but they do want to be ready as soon as the machine is clear. The best indication of this condition to the operator is auditory. It is interesting to see then, that if one adds an auditory reaction time—say 150 msec—to the machine maximum cycle time of 0·55 sec one gets 0·7 sec which is in fact where most sorting times occur. It seems certain that a machine which permits an operator to sort at his own pace, so long as his pace does not become faster than 0·55 sec, is not fast enough—the operators are unavoidably being delayed by the machine.

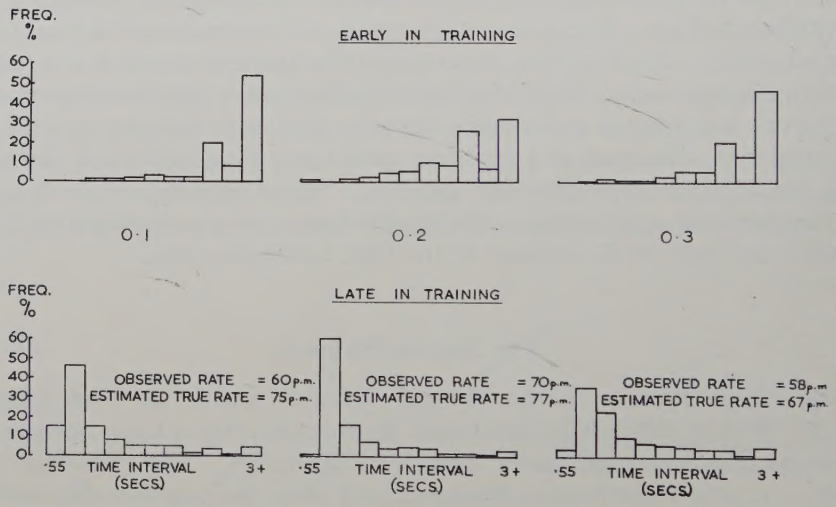

Figure 3. Distribution of the time required to sort a letter by machine.

§ 6. Conclusion

As a subject for ergonomics research, the field of telecommunications has the particular interest of its wide-spread ramifications in the life of the nation. Distant communication between people by letter or voice touches everyone. On one hand this means that the communication channel must be a very large industry, with problems affecting many operatives and dealing with ' work units ' running into many millions annually, so that a saving of a very small amount of time per unit becomes of importance. On the other hand the input and output ends of the system involves at least every adult in the community. This means that the system must be so designed that everyone understands how to use it, and is able to do so. No selection is possible, and that half of the population which is below average intelligence must also be catered for. This is a challenge to human science which comes but rarely.

I am indebted to the General Post Office and to the Union of Post Office Workers for invaluable co-operation in the studies mentioned in this paper.

Les quatre exemples cités dans cet article ont pour but d'illustrer comment appliquer les méthodes et principes de la psychologie expérimentale à des problèmes pratiques de télécommunications.

(1) En se basant sur la théorie de l'oubli dans la mémoire immédiate, on a pronostiqué, en termes d'erreurs, les efficacités respectives d'un cadran de téléphone et d'un dispositif équivalent utilisant une série de 10 boutons. On a également fait des pronostics quant à l'effet d'un chiffre préfixe sur la précision du rappel. L'expérimentation a largement confirmé ces prévisions théoriques.

(2) Des expériences de laboratoire devaient permettre l'étude des facteurs relatifs à la structure du numéro de téléphone de façon à en assurer un rappel facile. On a pris en considération les facteurs suivants : la longueur de la série ; son groupement ; le choix entre lettres et chiffres.

(3) Afin d'étudier l'effet de la densité du trafic sur la performance d'un opérateur-standardiste, on a soumis à une investigation expérimentale, pendant une durée de 5 semaines, un central téléphonique. Il est apparu que le temps mis par le standardiste pour établir une liaison était une fonction de la densité de trafic par opérateur.

(4) On a déterminé, en situation réelle, la courbe de distribution des temps nécessaires au tri de lettres effectué par pression sur une touche. On a mis en évidence un effet d'apprentissage et un effet limitatif du rendement introduit par des délais mécaniques.

Es werden 4 Beispiele angeführt, um die Anwendung der Methoden und Prinzipien der experimentellen Psychologie auf praktische Fernmelde-Probleme zu illustrieren :

(1) Die Theorie des Kurzgedächtnis-Schwundes wurde benutzt um die relativen Vorteile, ausgledrückt durch die Feherzahl, der Telefon-Wählscheibe im Vergleich zu einem Satz von 10 Druckknöpfen vorherzusagen.

(2) Laboratoriums-Experimente wurden benutzt, um die Faktoren zu untersuchen, die bei der Bildung langer Telefon-Codes für ein leichtes Behalten wichtig sind. Die berücksichtigten Faktoren waren : Länge ; Gruppierung ; Buchstaben gegen Zahlen.

(3) Eine Versuchs-Telefon-Anlage wurde 5 Wochen lang in einem Experiment über die Wirkung verschiedener Gesprächsbelastung auf die Leistung der Telefonisten benutzt. Es zeigte sich, dass die Zeit je Ruf eine Funktion der Gesprächszahl je Telefonist ist.

(4) Die Häufigkeitsverteilung der Zeit für Briefsortieren durch Knopfdrücken wurde in der Praxis aufgezeichnet. Der Einfluss der Uebung wurde dargestellt und der Einfluss der Mashinenzeit auf die Begrenzung der Leistung demonstriert.

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THERMAL STRESS IN A SINGLE STOREY FACTORY

By June I. Grieve

Physiological Unit, Post Office Research Station, Dollis Hill, London

Environmental conditions in a single storey factory were investigated as a result of staff complaints in summer when the external temperature rose to 74 deg. F. The Bedford corrected effective temperature scale was used to assess the thermal conditions, from measurements of air temperature, heat radiation, humidity and air movement in ten different parts of the factory. For the greater part of the day, the conditions were found to lie outside the Beford Confort Zone for light work. Measurements of energy expenditure were made in two areas of the factory, i.e. where the worst environmental conditions were found, and where the greatest physical work was involved, to determine whether all the work in the factory was in the light work category of the B.M.A. classification of work. The Wolff IMP respirometer was used to make direct measurements of energy expenditure. In one area, an indirect estimate of energy output was also made by the method of activity sampling, to compare with the direct measurements. The results showed that a significant thermal load is imposed by the environment on those engaged on light work as well as moderate work. Heat radiation from a glass roof and low air movement were the chief sources of the thermal load. Both these factors are commonly found in single storey buildings and they can produce considerable heat stress under summer conditions.

§ 1. Introduction

Extreme environmental conditions are sometimes found in industry. Where this occurs, special measures are obviously necessary to reduce stress on the workers and to control exposure times. There are also industrial environments where conditions become uncomfortable at certain times of the year. It may still be possible to work in these conditions, but staff complaints, sometimes numerous, may result in loss of working time ; conditions may often be uncomfortable enough to cause some loss of efficiency. The present paper describes an example of the latter situation in a single storey factory, of a type in common use in industry, where telecommunications equipment is repaired. The staff complained of discomfort, particularly in the summer when the outside temperature rose above 70°F.

The factory buildings are of single storey construction with ridged roofs. The lowest point of each roof is 12 ft and the roof apex is 21 ft above the level of the factory floor. The roof slope is symmetrical on either side at an angle of 22°, with a line of glazing 6 ft wide on northern and southern slopes. Heating and ventilation of the factory is by a plenum system with one unit per roof, consisting of a circular trunk and five outlets extending downwards and ending at 10 ft above the ground. Under instructions from the ventilation engineers, the windows at the east and west ends of the bays are kept closed to ensure efficient operation of the plenum system ; each plenum unit delivers air at 9500 ft^3/min.

§ 2. Method

2.1. *Measurement of Corrected Effective Temperature*

The first stage in the investigation was to assess the environment in the factory under summer conditions. Measurements were made at ten stations, scattered throughout the factory and chosen in collaboration with the staff representatives. A Dexion stand was erected at each station where measurements were to be made. Wet and dry bulb thermometers and a black globe

thermometer were hung from the stand at each of four levels :—

(*a*) floor level
(*b*) bench level, 3 ft above floor,
(*c*) head level, 6 ft above floor,
(*d*) roof truss height, 12 ft above floor.

SUMMER TEMPERATURE CONDITIONS

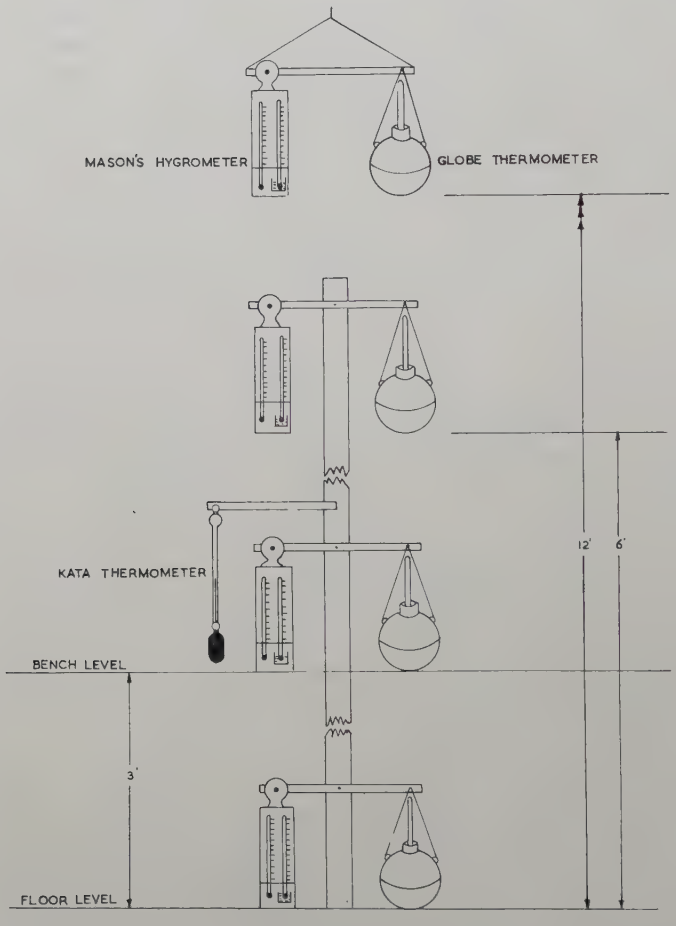

Figure 1.

Readings of the thermometers were made at each of the four levels at hourly intervals throughout the working day. The observer started at station 1 and completed all ten stations in turn. An unventilated wet bulb tends to give inaccurate, high readings. Therefore check readings with a whirling hygrometer were made when possible. The dry bulbs were shielded from radiation when necessary. Air velocity was measured with a kata thermometer at each of the ten stations. Three consecutive measurements of cooling time were measured at different times and on different days to obtain an average value of air velocity at each of the ten positions. From the readings obtained, values of humidity and heat radiation were calculated. The corrected effective temperature (Bedford 1936) was then computed using the values of black globe

thermometer, wet bulb temperature and air velocity. The scale of corrected effective temperature was used to assess the discomfort imposed by the environment since it takes account of the combined effects of air temperature, humidity, air movement and heat radiation. Equivalent temperature takes no account of humidity and effective temperature omits heat radiation ; therefore they are inadequate in assessing the stress on the body when the temperature is likely to rise above 70°F or when there is a source of heat radiation.

2.2. *Measurement of Energy Cost of Work*

Thermal stress on the body not only depends on the environment but also on the heat production of the body. When the physical effort increases, it becomes more difficult for the body to lose heat to a given environment. In order to determine the heat production of the body under working conditions measurements of the metabolic cost of work were made in two areas of the factory :—

(1) Where the worst environmental conditions were found—D3 shop, Figs. 2 and 3

(2) Where the greatest physical work was involved—cabinet shop, Fig. 4.

Figure 2.

The IMP Respirometer (Wolff 1958) was used as it can be worn conveniently for long periods of time and causes minimal interference with movements of the body at work. It was not possible to make a continuous study of energy expenditure throughout the working day, due largely to lack of investigating staff. Therefore the following routine was employed. Each subject wore the IMP respirometer for a preliminary period of about 15 min to become accustomed to the mask. Readings of ventilation volume were then taken over the ensuing period of 65 min. Three samples of expired air were collected during this period and subsequently analysed with a Haldane gas analysis apparatus.

Figure 3.

From these measurements an estimate of the mean rate of working was obtained. Four subjects were studied in the cabinet shop. The work here involves inspection and repair of wooden cabinets used for telephone switchboards. The surface of each cabinet is prepared by planing and scraping, leaving a new surface to be polished in the spray polishing shop. Measurements were also made on five subjects in D3 shop. Here the work involves repair to light telecommunications equipment, e.g. cleaning, assembling, wiring and soldering. Some of the work is done sitting at a bench and some standing.

Figure 4.

2.3. *Activity Sampling*

In order to provide the basic data for the estimation the daily energy expenditure of the staff, the method of activity sampling was used in the cabinet shop. The work was broken down into eight activities on the basis of known differences in energy cost : sitting ; standing ; sitting manipulating ; standing manipulating (including screwing, chiselling, etc.) ; planing and scraping ; lifting ; walking ; miscellaneous (out of room). A Powers Samas hand punch was used with an activity allotted to each key, following the method described by Wolff (1959). Groups of six subjects were observed simultaneously and the activity of each subject was recorded every 3 min throughout the working day on punched cards. In this way some 3 000 observations were obtained and analysed to give the proportions of time spent in each activity. There is a large amount of data on the energy cost of many different activities available in the physiological literature, thus, when the amount of time spent on each activity is known, it is possible to calculate the total energy expenditure by a weighting procedure.

§ 3. Results

3.1. *Environmental Temperatures*

The temperature readings obtained for the period from 17th July to 1st August 1957 at each of the ten stations were plotted graphically. The results shown are those obtained in D3 shop and the cabinet shop at bench level on a day with maximum dry bulb temperature at 74°F and 10·2 h sunshine.

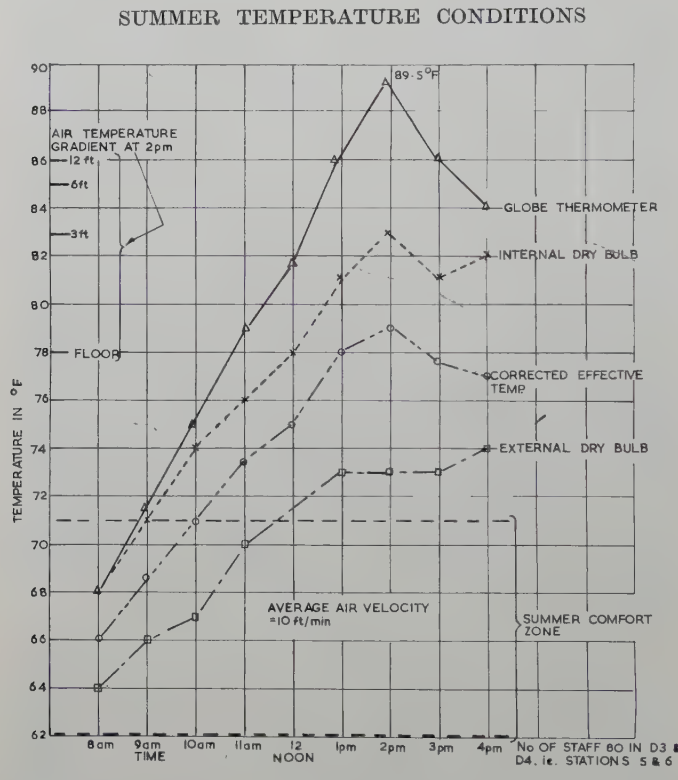

Figure 5. 30/7/57 Station 5. D3 & D4 Shop. 3ft above ground level.

The limits of the Comfort Zone suggested by Bedford (1936) for light work in summer are inserted on the graph, i.e. 62°F–71°F corrected effective temperature. It can be seen from the graphs that the corrected effective temperature lies outside the comfort zone after 10·0 a.m. There is a considerable amount of heat radiation present shown by the large difference between the readings of the black globe thermometer and dry bulb thermometer. The difference is greatest at the higher levels suggesting that the roof glazing is the main source of heat radiation. In some areas, e.g. D3 shop, there was also a large difference at bench level produced by heat radiation from soldering irons and bench lights. Comparison of air temperature at different levels at the same time show a temperature gradient as large as 7°F from floor to head level in some areas. Air velocities as low as 10 ft/min were recorded at bench level.

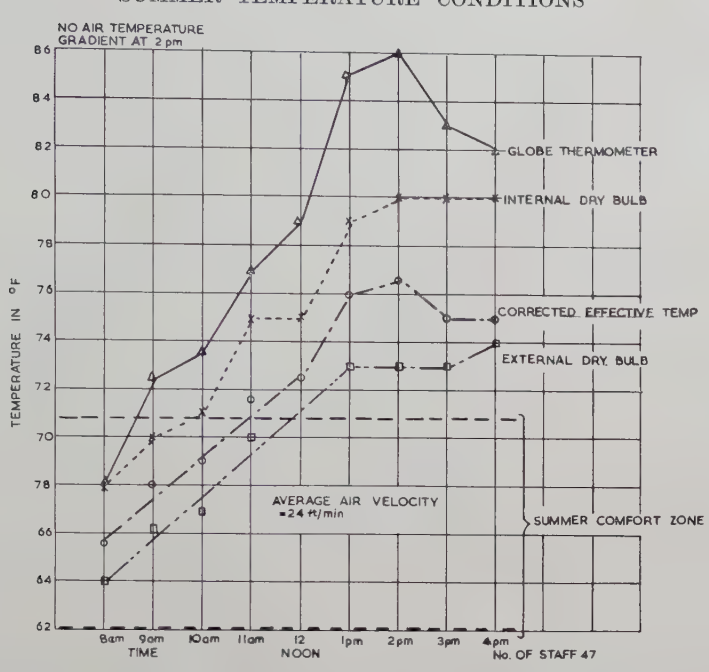

Figure 6. 30/7/57. Station 4. Cabinet shop. 3 ft. above ground level.

3.2. *Energy Expenditure*

The values of mean rate of working obtained with the IMP respirometer show a significant difference between the work in the cabinet shop and in D3 shop. The average value of 3·26 kcal/min for work in the cabinet shop lies in the ' moderate work ' category of the B.M.A. classification of work (British Medical Association 1950). The light repair work in D3 shop lies in the ' light work ' category of the B.M.A. classification with an average rate of 2·36 kcal/min. A table of total daily energy expenditure in the cabinet shop was compiled.

Table 1. Energy Expenditure Values

Subject	Work	kcal/min	Subject	Work	kcal/min
1	Cabinet repair	3·93	5	Repairing switchboards	2·23
		3·09			2·25
					2·38
2	Cabinet repair	3·22	6	Wiring bell sets	1·88
		3·59			1·86
		3·92			1·73
3	Cabinet repair	3·12	7	Assembling bell sets	2·30
		3·31			3·10
		2·62			2·55
4	Cabinet repair	2·78	8	Modification to amplifier panels	2·90
		3·39			2·49
		2·84			2·44
			9	Assembling and wiring switchboards	2·30
					2;78
					2·22
	Average	3·26		Average	2·36
	Moderate work (BMA classification)	2·9 to 4·5		Light work (BMA classification)	<2·9

The times spent on each activity were obtained from the activity sampling results. The energy cost of each activity was found from values given in the physiological literature (Passmore and Durnin 1955). The total energy expenditure for 8 hours work in the cabinet shop obtained in this way is 1643 kcal, i.e. the average rate of working is 3·42 kcal/min.

Table 2. Table of Estimated Daily Energy Expenditure (Cabinet Shop)

Activity	Time spent (per cent)	Energy cost* (kcal/min)	Total energy cost (kcal)
Sitting	13·1=62·9 min	1·6	100·6
Sitting manipulating	1·0=4·8 min	1·9	9·1
Standing	19·2=92·2 min	1·8	165·9
Standing manipulating	31·6=151·7 min	2·0	303·4
Planing and scraping	20·7=99·4 min.	8·0	795·2
Lifting	1·4=6·7 min	4·0	26·8
Walking	8·1=38·9 min	5·0	194·5
Miscellaneous	4·9=23·5 min	2·0	47·0
Total	8 hours' work	—	1642·5
Average	8 hours' work	—	3·42 kcal/min

* Values obtained from R. Passmore and J. V. G. A. Durnin, 1955, *Physiological Reviews*, **35**, 801.

3.3 *Thermal Stress*

When the metabolic cost of work is shown and the environmental conditions are specified it is possible to estimate the heat stress on the body. The amount of heat lost by the body by radiation and convection in a given environment depends on the globe thermometer temperature and air velocity. It is represented by Belding and Hatch (1955) by the following equation :—

$$(R+C)=(22+2\sqrt{V})\ (tg-95)$$

where tg = globe thermometer temperature
and V = air velocity.

If the body is in thermal equilibrium, the heat lost will be sufficient to balance the heat produced by metabolism. If the metabolic heat exceeds that lost from the body surface by radiation and convection, the excess heat must be dissipated by evaporation of sweat, which is limited by the vapour pressure and air velocity. Table 3 shows that in both areas of the factory there is a heat load of some 400–500 B.T.U./hr which must be dissipated by evaporation of sweat. Conditions can be improved by an increase in the air velocity and reduction of the globe thermometer temperature, so that more heat can be lost by convection and radiation to balance the heat produced by metabolism.

Table 3. Heat Stress Data

	D3 shop	Cabinet shop
External dry bulb	74°F	74°F
Number of hours sunshine	10 h	10 h
Internal dry bulb	83°F	80°F
Globe thermometer	89°F	86°F
Air velocity	10 ft/min	24 ft/min
Heat loss by radiation and convection	170 B.T.U./hr	286 B.T.U./hr
Heat produced by metabolism	562 B.T.U./hr	779 B.T.U./hr
Excess heat to be dissipated	392 B.T.U./hr	493 B.T.U./hr

§ 4. *Discussion*

The investigation established that a physiologically significant thermal load is imposed on the body by the environmental conditions in some parts of the factory at times when the external temperature rises to 74°F. The worst conditions were encountered in D3 shop in one of the central bays of the factory ; the work in this area is light with an energy expenditure of 1·78–3·12 kcal/min. In the cabinet shop, however, the environmental conditions are better than in D3 shop but the higher level of energy expenditure of the work (2·60–3·90 kcal/min) means that the thermal load imposed on the body is approximately the same as in the D3 shop.

The values of mean working rate in the cabinet shop obtained by the direct method using an IMP respirometer (3·26 kcal/min) and by the method of activity sampling (3·42 kcal/min) show good agreement. As more and more direct energy measurements of industrial tasks become available, it will be possible to make simple and accurate estimates of the total energy expenditure of the work period by the aid of activity sampling alone.

Since this investigation was concluded, conditions in the factory have been improved. Heat radiation from the glass roof has been reduced by the use of roof shading. The convective heat gain is also reduced in this way through lowering of the temperature of the roof. Some increase in air movement has been achieved by diversion of most of the air from one main trunk of the plenum system into areas where most people work and a reduction of the air entering store areas where few people work. Powered extractors have been installed in the roof ridges of the central bays to create an additional source of ventilation. In this way the corrected effective temperature has been lowered.

There is considerable evidence that poor ventilation and sources of heat radiation are critical factors in determining comfort at work in single storey factories. Therefore, these are two important considerations for designers of such buildings.

I wish to express my thanks to Dr. W. F. Floyd, Consultant Physiologist to the Post Office, for helpful discussions and advice during the course of the work and to Mr. F. A. L. Goddard of Post Office Factories Department who assisted in the organization of the investigation.

Acknowledgment is made to the Engineer-in-Chief of the Post Office for permission to make use of the information contained in the paper.

Les difficultés éprouvées par le personnel lors de températures extérieures de l'ordre de 74° F (23° C) ont été à l'origine d'une étude sur les conditions d'environnement dans une usine à un seul étage. On s'est servi de l'échelle des températures effectives corrigées (échelle de Bedford) pour évaluer les conditions thermiques. Les mesures nécessaires, telles que température de l'air ambiant, radiation, humidité et vitesse de l'air ont été enregistrées dans dix endroits différents de l'usine. Il s'est avéré que pendant la majeure partie de la journée, les conditions se situaient, pour un travail léger, en dehors de la zone de comfort de Bedford. On a procédé à des mesures de dépense énergétique en deux endroits difiérents de l'usine, là, en particulier, où les conditions extérieures de travail se trouvaient être les plus pénibles et où le travail musculaire était le plus astreignant. Ceci pour pouvoir déterminer si le travail global de l'usine pouvait être classé dans la catégorie " travail léger " de la classification du B.M.A. (British Medical Association). Le spiromètre I.M.P. de Wolff a servi aux mesures des dépenses énergétiques. Et un endroit de

l'usine, on a également utilisé une estimation indirecte de la production énergétiques par la méthode de l'échantillonnage des activités, ce qui devait permettre une comparaison avec la méthode de mesure directe.
Résultats : Une charge thermique importante est imposée par les conditions d'environnment aussi bien aux ouvriers qui effectuent un travail léger qu'à ceux qui accomplissent un travail moyen. Les radiations provenant de la verrière du toit et la faible convection se sont avérées être les causes principales de la charge thermique. Ces deux factuers se retrouvent fréquemment dans des bâtiments à un seul étage et sont responsables de la charge de chaleur en été.

In einer einstöckigen Fabrik, in der sich die Belegschaft über Hitzebelastung beklagte, wenn die Aussentemperatur im Sommer über 23° C. steig, wurden die Umgebungsbedingungen untersucht. Die korrigierte effektive Temperatur-Skala nach BEDFORD wurde benutzt, um die thermischen Bedingungen aufgrund von Messungen der Lufttemperatur, der Wärmestrahlung, der Feuchtigkeit und der Lufttbewegung in 10 verschiedenen Teilen der Fabrik festzustellen. Den grössten Teil des Tages lagen diese Bedingungen ausserhalb der BEDFORD'schen Behaglichkeitszone für leichte Arbeit. In 2 Bezirken der Fabriken wurde der Energieaufwand gemessen. Es handelte sich um Bezirke, in denen die schlechtesten Umgebungsbedingungen herrschten und die schwerste körperliche Arbeit verlangt wurde. Es sollte ermittelt werden, ob die gesamte Arbeit in der Fabrik in der Kategorie der leichten Arbeit nach der British Medical Association-Klassification lag. Das WOLFF-I.M.P.-Respirometer wurde verwendet, um den Energieaufwand direkt zu messen. In einem Bezirk wurde auch eine indirekte Schätzung des Energieumsatzes mit der Methode der Tätigkeits-Stichproben-Ehrebung unternommen, um einen Verglech zur direkten Methode zu gewinnen. Die Ergebnisse ziegten, dass sowohl die mit leichter Arbeit, wie auch die mit mittel-schwerer Arbeit Beschäftigen, eine erhebliche Hitzebelastung erleiden. Wärmestrahlung vom Glasdach und zu geringe Luftbewegung waren die Hauptursachen der Hitzebelastung. Beide Ursachen finden sich gewöhnlich in einstockingen Gebäuden. Sie führen zu beträchtlicher Wärmebelastung in Sommer.

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HEAT STRESS AND ATHLETICS

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This paper briefly reviews certain aspects of man's response on exposure to a hot climate. The value of applying the concepts of thermal exchange analysis to evaluate the severity of a particular heat stress situation is emphasised. The possible effects of the Rome climate on a marathon runner competing in the 1960 Olympic Games is used as an illustration. It is concluded that with more knowledge of the physiology of athletes the accuracy of such predictions could be much increased, and might then be helpful to the athlete in planning the strategy of his race.

§ 1. Introduction

This paper briefly reviews certain aspects of man's response on exposure to a hot climate and, in particular, discusses how a hot climate might affect a marathon runner. The thermal stress of a hot climate is determined by the combined effects of all the climatic factors which influence the loss or gain of heat by the body—air temperature and humidity, air speed, radiation and barometric pressure. The effect of a hot climate on a particular individual depends on further factors which characterize the state of the individual—energy expenditure, clothing, body size, degree of acclimatization, duration of exposure and the general health of the individual concerned.

The ways in which an individual loses or gains heat are shown in Fig. 1. During severe exertion the heat produced by metabolism is very considerable, and unless all this heat is eliminated the body temperature will rise. In really hot climates the air temperature may be higher than the skin temperature, and in such conditions not only must all the heat of metabolism be lost by sweating but also additional sweat must be evaporated to remove heat absorbed from the air by convection. Likewise, in sunny conditions relatively large amounts of heat may be absorbed from solar radiation.

In considering the mechanisms whereby the flow of heat to the environment is controlled it is useful to remember that there are three important temperatures—deep body temperature, skin temperature and air temperature—and between these three reference temperatures there are two regions of heat flow (Fig. 2). The rate of heat flow in region A is influenced by the temperature difference T_1–T_2 and the rate of blood flow from the deeper tissues to the skin. The blood may be considered as acting as the coolant in a heat exchanger system, picking up heat from the muscles and internal organs where it is produced by metabolism and losing it again at the skin capillaries. The rate of heat flow across the region B is determined by the temperature difference T_2–T_3 and the other environmental variables which determine the cooling power of the air surrounding the body. Evaporative cooling by sweat secretion is a special mechanism for promoting heat flow across this region. It is clear that the skin temperature occupies a key position since an increase will promote the flow of heat in region B and impede it in region A. So, in order to calculate the magnitude of thermal exchange through the various avenues it is necessary to predict or measure the skin temperature.

§ 2. Effects of Heat Stress

There are three principal ways in which the body can respond when exposed to a heat stress. The first is to increase the rate of blood flow through the skin

so that a large amount of heat can be transferred between deep body tissues and the skin surface with only a small difference in temperature between T_1 and T_2. The second is to lower T_2 by sweat secretion, thus promoting heat flow by increasing the temperature difference between T_1 and T_2. The third is to utilize the heat storage capacity of the body. In prolonged exertion the amount of heat that can be stored is too small to be of great importance since,

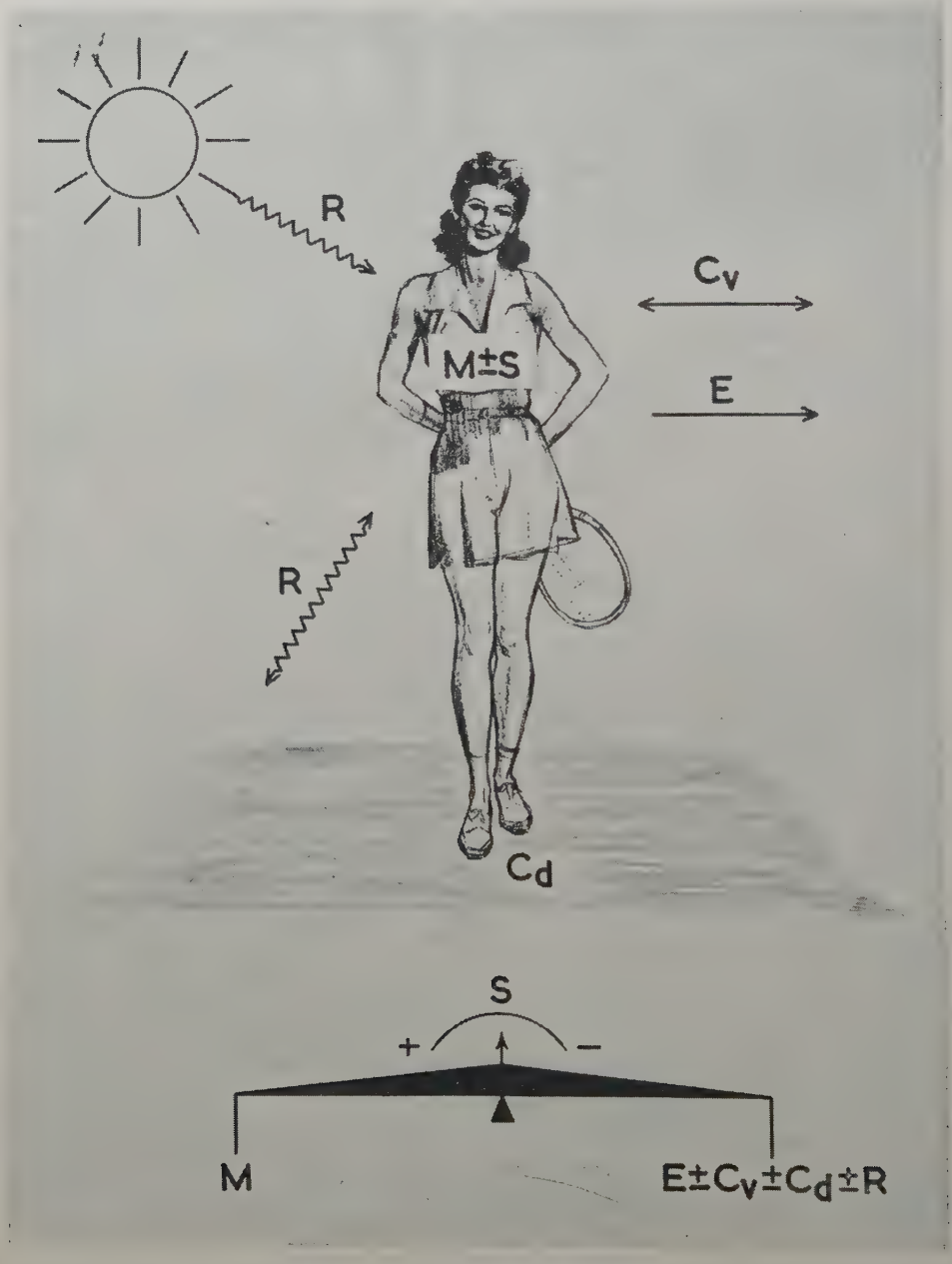

Figure 1. Diagram to illustrate the avenues of therma exchange between an individual and the environment. M=metabolism ; S=storage ; E=evaporation ; C_v=convection ; C_d=conduction ; R=radiation.

after peripheral vasodilatation has taken place, the expenditure of only 50 kcal by an average-sized individual will raise the deep body temperature by about 0·5–1·0°c. However, it is also beneficial in promoting a greater heat loss by increasing the temperature gradients between the body core and the environment.

Increasing the blood flow through the skin imposes a strain on the cardiovascular system and diverts a part of the maximum cardiac output which would otherwise be available for supplying the muscles. If the somewhat bold assumption is made that the rate of blood flow through forearm skin (Edholm *et al.* 1956) is representative of the average rate through the skin of the rest of the body surface, in the fully vasodilated state as much as 10 l./min of the total cardiac output may be flowing through the skin alone.

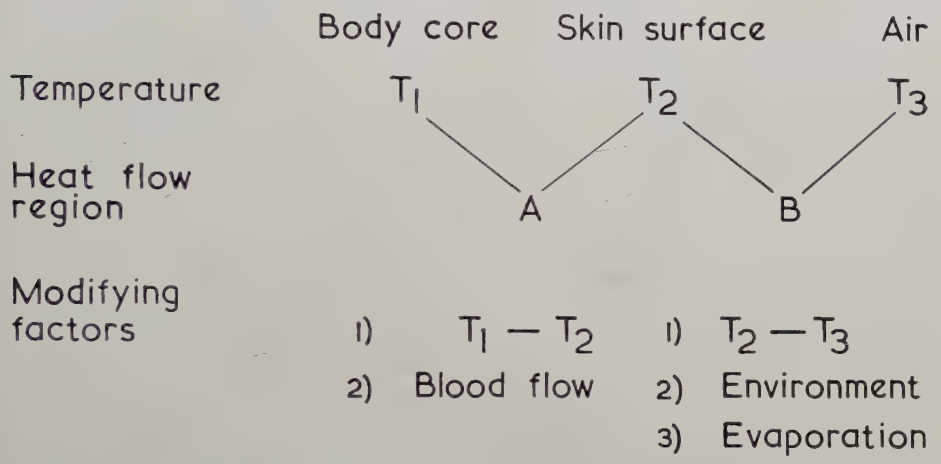

Figure 2. Schematic diagram of heat flow gradients and factors modifying heat flow.

Secretion of sweat involves the loss of body fluid, which throws a strain on the cardiovascular system by reducing the available blood volume. In addition, electrolytes—especially salt—are lost and if not replaced can eventually lead to symptoms of deficiency. Finally, an excessive increase in body temperature from heat storage embarrasses the essential physiological processes of the body and leads to collapse.

The changes occurring during the early days of exposure to heat and which constitute the process of acclimatization should be considered against this background of the avenues of thermal exchange between the body and its environment and the physiological mechanisms available to the body for combating a situation with a high thermal stress.

If an individual is suddenly exposed to a hot climate, and especially if he also has to work hard in it, he rapidly becomes distressed. The symptoms may include fatigue, headache, dizziness, abdominal cramps and nausea ; the signs may include flushing of the face and neck, rapid pulse, lack of co-ordinated effort (clumsy, stumbling) and a raised body temperature. If the individual persists he may vomit or collapse (Bean and Eichna 1943). There may also be minor or severe mental disturbances. These may take the form of emotional changes such as euphoria, moroseness or irritability ; in addition, the judgment

and mental capacity of the individual may be impaired (Ellis *et al.* 1953). With repeated exposure to work in hot climates these symptoms become less severe, and after about a week the process of adaptation is about 80 per cent complete (Robinson *et al.* 1943).

It would seem that the total improvement is the result of the summation of a number of small changes. Sweating starts earlier (Ladell 1947), is more profuse (Eichna *et al.* 1950, Hellon *et al.* 1956, Bass *et al.* 1955), and if the salt intake is low the amount lost in the sweat falls (Adolph and Dill 1938, Conn, 1949). The heat exchanging function of blood circulation becomes more efficient, partly because there is an increase in blood volume (Robinson, 1949) and probably also because the heart and blood vessels become used to the additional load. The increase in cardiovascular efficiency is shown by a smaller rise in pulse rate with work in the heat (Bean and Eichna 1943 ; Bass *et al.* 1955). The improved cardiovascular efficiency and increased sweating combine to produce a smaller rise in deep body temperature and lower skin temperature (Robinson *et al.* 1943).

These changes can all be measured objectively, but the most striking change and the hardest to measure is the reduction in subjective discomfort. An individual who may be exceedingly miserable on the first day of exposure to a hot climate, even collapsing or being forced to give up, may suffer little or no distress after 7–10 days of repeated exposures.

To develop maximum acclimatization it seems to be necessary to work hard in the hot climate as well as being exposed to heat, and it might be advisable to grade the stress so that as the individual adapts the intensity of the heat exposure is increased (Bean and Eichna 1943). This can be done either by increasing the thermal stress of the climate (if this is controllable, as in a hot room) or by increasing the rate of energy expenditure. Acclimatization is probably quite quickly lost once the individual ceases to be exposed (Bean and Eichna 1943, Stein *et al.* 1948–49, Adam *et al.* 1960).

§ 3. The Problem of the Marathon Runner

If the weather is as hot, or hotter, than the average values for the 10-year period shown in the table, heat stress may prove to be an important problem at the Olympic Games in Rome this year. Athletes, like the long-distance runner, who have to maintain a high rate of energy expenditure over long periods are particularly liable to be affected. Although it is now known that the marathon will be run in the afternoon, when conditions should be easier, for the purpose of illustration let us consider the hypothetical case of a marathon runner competing in the average conditions for the hottest time of the day—dry-bulb 85°F, wet-bulb 69°F. It may be assumed that the average air speed over his body will be that caused by his own movement, i.e. 10 m.p.h. The sun is likely to be shining (see table), so some allowance for radiant heat is necessary. The globe thermometer is an instrument that has been widely used to provide an indication of the radiation intensity and a reading of 115°F on this instrument seems a reasonable guess. The radiation increment for the man is likely to be considerably less, partly because much of the radiation will come directly from the sun striking the runner from above, thus minimizing the area exposed, and partly because of losses through the reflection and

absorption characteristics of his skin and clothing. For these reasons a radiation increment of only 10°F has been used in the calculations which follow.

The marathon runner should expend about 1000 kcal/hr (Handbook of Biological Data, 1956) for the $2\frac{1}{2}$ hours of his race. Almost all this heat, produced by muscular exertion, must be eliminated from the body during the race and mainly through the evaporation of sweat. The amount of sweat needed to maintain thermal equilibrium can be calculated using the technique of

Meteorological data for Rome in July, August and September, based on the averages over a 10-year period (by courtesy of the Air Ministry, London).

	July	August	September
Temperature (°F)			
Average daily maximum	88	88	83
Average daily minimum	64	64	61
Absolute maximum	101	102	104
Absolute minimum	51	49	50
Relative Humidity (%)			
Average at 0600	70	73	82
Average at 1300	42	43	50
Average Sunshine (*hr*)	11·2	10·0	7·0

thermal exchange analysis developed by the J. B. Pierce Laboratory (Winslow, Gagge and Herrington 1940, Winslow, Herrington and Gagge, 1936 a, b, 1937 a, b) and as applied by Haines and Hatch (1952). A second method is to use the Predicted Four-hour Sweat Rate nomogram of McArdle *et al.* (1947). From both these lines of enquiry it seems that the marathon runner would have to produce $1\frac{1}{2}$–2 litres per hour, or a total of 4–5 litres during the race. This raises the question as to whether such a high rate of sweating is within the capacity of the runner's sweating mechanism. Fit, fully acclimatized young men can normally produce 1–$1\frac{1}{2}$ l./hr for periods of 4 hours (McArdle *et al.* 1947) and as much as 2 l./hr for 4 hours has been recorded (Adam *et al.* 1955).

Assuming the marathon runner to be one of the fortunate individuals capable of producing enough sweat, it is necessary to determine whether it could all be evaporated. If he were uniformly wetted by his sweat over the whole body surface it appears that enough could be evaporated while he is running. As soon as he stopped, however, the air speed over his body would fall and then the maximum evaporative capacity would be drastically reduced. This sudden reduction in the heat eliminating ability at the end of a long race, with a consequent rise in skin temperature and its tendency to produce peripheral vasodilatation, may well be a factor in precipitating collapse through circulatory failure.

Finally, it is necessary to enquire what effect the loss of such a large volume of fluid will have on the runner's performance. It is difficult to make any prediction except to say that with the circulation already extended by the

demands of both metabolism and temperature regulation, the withdrawal of even a relatively small quantity of body fluid would be expected to affect performance adversely.

With additional knowledge from studies on marathon runners while actually performing in hot conditions, it should be possible to increase the accuracy of such predictions considerably. Immediately before a race, and armed with precise climatic data, the physiologist might be able to advise the intending athlete how serious an obstacle the heat stress would be and help him to plan the strategy of his race accordingly.

The author wishes to acknowledge the help of the Meteorological Office of the Air Ministry who provided the climatic data for Rome.

Editor's Note: This paper was accepted for publication before the Olympic Games. It is based on a paper, "Short Term Adaptation to Heat" (see summary in *Ergonomics*, 3, 1, 1960, p 88), presented by Dr. Fox to a joint meeting of the Ergonomics Research Society and Central Council for Physical Recreation, on 19 June, 1959.

Cet article passe brièvement en revue un certain nombre d'aspects concernant la réaction de l'organisme humain lors d'une exposition à des températures élevées. On souligne l'importance de l'utilisation des principes de l'analyse des échanges thermiques pour évaluer la sévérité d'une situation particulière de charge de chaleur. Comme illustration, on cite les effets possibles du climat de Rome sur un coureur de Marathon lors des Jeux Olympiques de 1960. Une meilleure connaissance de la physiologie des athlètes, est-il dit en conclusion, pourrait fortement augmenter la précision de tels pronostics et, par suite, aider l'athlète à mettre au point la stratégie de sa compétition.

In dieser Arbeit wurden einige Reaktionen des Menschen bei Aufenthalt in einem heissen Klima besprochen. Es wird betont, wie nützlich es ist, die Begriffe der Wärme bilanz zur Bewertung der Schwere einer Hitzebelastung zu verwenden. Zur Illustration werden die möglichen Folgen des römischen Klimas auf einen Marathon-Läufer während der Olympischen Spiele 1960 erörtert. Es wird geschlossen, dass bei besserer Kenntnis der Sportphysiologie genauere Voraussagen zu machen währen. Das könnte dem Sportler für die Planung seines Laufes nützlich sein.

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AN ANALYSIS OF SOME FACTORS INFLUENCING SEAT COMFORT

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This study presents a re-analysis by correlation and factor analysis of data on the relative comfort of six Air Force pilot and crew seats. On the basis of the results obtained, the following conclusions may be drawn:

1. Seats are rated in the same relative order of comfort after only 5 min of sitting time has elapsed as after 4 or more hours of sitting on the seats.
2. People tend to rate the overall comfort of a seat mainly on the basis of the comfort of their backs and buttocks. The comfort of the neck and shoulders plays a secondary role while thigh and leg comfort seems to have little relationship to judgements of the overall comfort of a seat.

It was found that the following seven types of measurements were measures of the same quantity, Overall Comfort of a seat:

(*a*) Actual time a subject is willing to sit in a seat (up to a maximum of seven hours).
(*b*) Ratings of overall comfort after 5 min of sitting.
(*c*) Predictions of total time he would be willing to sit in the seat made after 5 min of sitting.
(*d*) Time of onset of first signs of discomfort.
(*e*) Ratings of overall comfort after 4 to 7 hours of sitting.
(*f*) Comfort of the back.
(*g*) Comfort of the buttocks.

§ 1. Introduction

Seat comfort is an increasingly popular item of discussion in all fields of transportation, particularly in the automobile industry. The major difficulty of measurement and evaluation is the lack of an accurate definition of 'comfort'. The term has a nebulous connotation ranging from absence of discomfort to positive feelings of pleasure. *Discomfort*, a much more easily identifiable state, can, however, serve as an indirect measure. This paper is concerned with a description of the factor structure of several criteria of seat comfort (or discomfort). The criteria and methods of data reduction suggested in this report represent the primary steps in a programme of research on seat comfort now under way at the General Motors Research Laboratories.

The paper has two aims. Firstly to demonstrate the applicability of the techniques of factor analysis and correlation to experimental data, in order to achieve a general clarification of a complex set of relationships and to generate hypotheses for future experimental verification. Secondly, the results of this particular analysis are of value in that they produce a relatively simple, testable model of seating comfort.

§ 2. Method

The data for the present analysis were taken from the study by Slechta *et al.* (1957) of six different aricraft pilot and crew seats, evaluated by 18 subjects with regard to the comfort provided. Three of the seats investigated were pilot seats, two were crew seats while the remaining was a minimal control seat. The pilot seats were: Seat 1 (made by Weber, classified 'Long Range') providing arm-rests, head-rest, adjustment of fore and aft and vertical position

and discrete adjustment of the included angle between the seat pan and seat back; Seat 2 (Weber, 'Gravity Load') providing the same features and adjustments through a somewhat wider range; and Seat 6 (Aerotherm) providing armrests, fore and aft and vertical adjustments and independent adjustment of the seat pan angle and seat back angle. The two crew seats, Seat 4 (Hardman, Model 605) and Seat 5 (Weber) provided neither armrests nor angular adjustments. Both provided some fore and aft and vertical adjustment, while Seat 5 was equipped with a headrest. The remaining seat, Seat 3, was a control seat constructed of uncontoured plywood, providing neither cushioning nor adjustability.

The primary criterion of seat comfort was the amount of time each subject was willing to sit in each seat, up to an arbitrary time limit of seven hours. During the sitting period, each subject was allowed to study but not to write and was permitted no conversation except with the test monitor. A number of rating scales were also included as subsidiary criteria. The following eleven criteria were selected for re-analysis:

1. Total voluntary sitting time.
2. Comfort rating after 5 min—measured on a 9-point scale ranging from -4 to $+4$. This rating was made by the subject after 5 min of sitting in the seat, and at hourly intervals throughout the sitting time.
3. The subject's own prediction of total sitting time, after 5 min of sitting in the seat. Predictions were made after 5 min and at hourly intervals throughout the sitting time.
4. Time of onset of discomfort—data taken from items 6–11 below. The time of onset of discomfort of any part of the body was recorded.
5. Subject's comfort rating after 4 to 7 hours of sitting time—measured on a 21-point rating scale, ranging from -10 to $+10$. This variable was a post-test questionnaire administered after each subject voluntarily ended his period of sitting.

6–11. Average discomfort in specific body parts. A 6-point scale ranging from 'none' to 'intolerable' discomfort was administered after 5 min of sitting and at hourly intervals throughout the sitting period. It was originally scored from 0 (no discomfort) to 5 (intolerable discomfort), but in order to avoid negative correlations, the scores for these six variables were converted to comfort scores by multiplying each score by -1. Thus, a high negative score indicates less comfort. The specific body parts evaluated were :

6—Neck,
7—Shoulders,
8—Back,
9—Buttocks,
10—Thighs,
11—Legs.

The data used in the analysis are shown in Table 1. Since some of these variables included a larger number of subjects than others, the mean values of all subjects' scores were used as the basic data. Correlations were calculated

Table 1. Scale Values for Items under Analysis

Seat No.	Sitting time in minutes	Comfort rating after 5 min	Prediction after 5 min in hours	Time of onset of discomfort in minutes after start of sitting	Comfort rating after 4 to 7 hours	Ratings for discomfort ($x-1$) in various parts of the body. The figures are the means of ratings given during the first 4 hours of sitting					
						Neck	Shoulders	Back	Buttocks	Thighs	Legs
	1	2	3	4	5	6	7	8	9	10	11
1	365·9	1·8	6·8	198·0	3·27	−1·2	−0·2	−1·6	−2·5	−0·2	−0·6
2	368·3	2·0	5·9	189·2	5·24	−1·0	−0·1	−1·8	−3·3	−0·3	−0·6
3	267·1	0·1	4·7	99·1	−5·29	−1·7	−1·1	−5·7	−8·2	−1·2	−0·4
4	309·9	0·7	5·4	112·6	−1·11	−1·8	−1·6	−3·4	−3·7	−6·2	−1·7
5	308·2	1·1	4·9	134·5	−0·97	−2·0	−1·5	−3·6	−6·2	−1·4	−1·0
6	400·4	2·5	6·5	220·0	6·59	−0·8	−0·1	−1·2	−1·4	−0·1	−0·3

using as ' scores ' the mean figures for each of the six seats evaluated. The sample size for each correlation was thus only six. This small sample was compensated for by the stability of the values used since each mean represented the scores of 15 to 18 subjects. It must be remembered, however, that correlation among means produces coefficients which are higher than those obtained when individual scores are used.

§ 3. Discussion of Results

The eleven variables were intercorrelated, producing the 55 intercorrelations shown in Table 2. A principal components factor analysis and a normal varimax axes rotation were then computed from the intercorrelation matrix, using an IBM 704 computer with a programme developed by the General Motors Research Laboratories. The factor loadings are shown in Table 3. The loading of a test on a factor indicates the amount of variance of that test which can be explained by the factor. The square of each loading gives the percentage of test variance accounted for by each factor. The meaning of a factor is obtained by an examination of the tests that load highly on it and the name is assigned on the basis of this examination.

Table 2. Intercorrelation matrix. The item numbers refer to the criteria in Table 1

Item No.	1	2	3	4	5	6	7	8	9	10	11
1	—	0·987	0·900	0·974	0·990	0·879	0·828	0·794	0·926	0·450	0·359
2		—	0·840	0·979	0·988	0·846	0·815	0·958	0·866	0·534	0·402
3			—	0·899	0·850	0·816	0·810	0·904	0·908	0·346	0·314
4				—	0·958	0·891	0·894	0·933	0·840	0·618	0·519
5					—	0·866	0·816	0·971	0·904	0·445	0·327
6						—	0·957	0·775	0·751	0·580	0·627
7							—	0·738	0·646	0·731	0·728
8								—	0·950	0·325	0·182
9									—	0·096	0·042
10										—	0·924
11											—

Table 3. Final factor matrix–normal verimax rotation. h^2=the sum of the squares of the two factor loadings

Item		Factor I	Factor II	h^2
1	Sitting time	*0·946*	0·317	995
2	Comfort rating after 5 min	*0·914*	0·342	953
3	Prediction of total sitting time after 5 min	*0·898*	0·220	855
4	Time of onset of discomfort	*0·882*	0·457	987
5	Comfort rating after 4 to 7 hours of sitting time	*0·947*	0·266	968
6	−1 × Discomfort in neck*	0·766	0·546	886
7	−1 × Discomfort in shoulders*	0·685	0·680	932
8	−1 × Discomfort in back*	*0·981*	0·114	976
9	−1 × Discomfort in buttocks*	*0·984*	0·059	972
10	−1 × Discomfort in thighs*	0·186	*0·933*	905
11	−1 × Discomfort in legs*	0·092	*0·966*	942

*(Average of first 4 hours of sitting time.)

Two orthogonal (independent) factors were found. These accounted for approximately 94% of the intercorrelation variance. Items 1, 2, 3, 4, 5, 8 and 9 loaded highly on factor I, while items 10 and 11 loaded most highly on factor II. Items 6 and 7 loaded almost equally on both factors.

Factor I evidently represents overall comfort as indicated by the high loadings of the two general comfort measures. Total sitting time (1) and comfort rating after 4 to 7 hours (5). The only sizeable loadings on this factor relating to parts of the body are back and buttock comfort (8 and 9). The lack of other high loadings relating to parts of the body indicates that the overall comfort of a seat seems to depend mainly on the comfort of the back and buttocks. The moderate loadings of neck and shoulder comfort (6 and 7) on this factor indicate that these parts of the body play some part in determining overall comfort but that their influence is probably secondary.

The high loading of the comfort rating after 5 min (2) on this factor indicates that comfort ratings made after this short period produce essentially the same results as ratings made after 4 hours of sitting. More important to the experimenter in this field, however, is the high correlation (0·987) between these 5 min ratings and total sitting time (1). This correlation permits us to predict fairly long term effects of sitting in a seat on the basis of a relatively short time sample.

Factor II shows high loadings for comfort in thighs (10) and in legs (11). The loading of these items on the overall comfort factor is essentially zero. This indicates that comfort or discomfort of the thighs and legs has no direct effect upon the subjective feelings of comfort of a seat. It may be inferred that once an individual is provided with good accommodations for his back and buttocks, he is willing to overlook any discomfort in thighs and legs and rate the total seat as comfortable. The high correlation between thigh and leg ratings indicates that the placement of foot rests and pedals may have an effect on both these body parts. The operating position of the thighs, therefore, should be given consideration in the design of foot controls.

It should be remembered that this discussion has centred around the physically based factors influencing seat comfort and that the analysis carried out concerned a factor analysis of comfort rather than an analysis of different seats. These results, therefore, should be applicable to any general types of seating configuration, and the factor structure derived from a different sample of seats should be similar to that obtained here. The factor structure could however easily change with the introduction of such variables as different tasks to be carried out while sitting in the seats, or with variations in the responses demanded of subjects or in seating attitudes.

The main practical contribution of this paper is a more precise definition of some of the variables influencing the overall impression of seat comfort. Further research is desirable concerning the influence of the separate body parts on overall comfort, and a thorough analysis of the hour-by-hour factor structure of the criterion is needed to present an accurate picture of any changes in the comfort of a seat which might occur as a function of prolonged sitting.

Cette étude reprend l'analyse, par les méthodes des corrélations et de l'analyse factorielle, de données concernant le confort assuré par six types de sièges de pilotes et d'équipages de l'Armée de l'Air. Sur la base des résultats ainsi obtenus, les conclusions suivantes peuvent être dégagées :

1. Les sièges font l'objet d'appréciations de confort similaires aussi bien après 5 min. seulement de position assise qu'après 4 heures ou plus.
2. Les sujets tendent à apprécier le confort global d'un siège en se fondant principalement sur le confort de leurs régions dorsales ou fessières. Le confort de la nuque et des épaules joue un rôle secondaire, tandis que le confort des cuisses ou des jambes semble n'avoir que peu d'influence sur l'appréciation du confort global d'un siège.

Il a été trouvé que le confort général d'un siège pouvait être évalué quantitativement par les sept types de données suivantes :

(*a*) Durée réelle pendant laquelle un sujet accepte de demeurer assis sur un même siège (cette durée pouvant atteindre sept heures).
(*b*) Appréciations de confort formulées après 5 minutes en position assise sur un siège.
(*c*) Prédiction de la durée totale pendant laquelle un sujet accepterait de demeurer assis sur un même siège, effectuée après qu'il soit demeuré assis pendant 5 minutes dans ce siège.
(*d*) Délai d'apparition des premiers signes d'inconfort.
(*e*) Appréciation de confort formulées après 4 à 7 heures passées assis dans un siège
(*f*) Confort de la région dorsale.
(*g*) Confort de la région fessière.

Diese Untersuchung gibt eine Neu-Bewertung früherer Daten über den relativen Komfort von Sitzen der Piloten und der Besatzung der Luftwaffe aufgrund von Korrelationem und einer Faktorenanalyse. Aus den Ergebnissen können folgende Schlüsse gezogen werden :

1. Sitze werden nach nur 5 min Sitz-Zeit in der gleichen relativen Komfort-Reihenfolge bewertet wie nach 4 und mehr Sitz-Stunden.
2. Man beurteilt den Gesamt-Komfort eines Sitzes hauptsächlich auf der Basis des Komforts des Rückens und des Gesässes. Der Komfort von Hals und Schultern spielt eine sekundäre Rolle, während der Komfort der Oberschenkel und Beine wenig Beziehung zum Gesamt-Komfort des Sitzes zu haben scheint.

Folgende 7 Messungen waren zugleich Messungen der Grösse des Gesamt-Komforts eines Sitzes :

(*a*) Die wirkliche Zeit, die eine Person gewillt ist, in einem Sitz zu sitzen (bis zu einem Maximum von 7 Stunden).
(*b*) Beurteilungen des Gesamt-Komforts nach 5 min sitzen.
(*c*) Vorhersagen der Gesamtzeit, die eine Person zu sitzen gewillt ist, nach 5 min Sitzen.
(*d*) Die Zeit des Beginnes der ersten Zeichen von Diskomfort.
(*e*) Beurteilungen des Gesamt-Komforts nach 4 bis 7 Stunden Sitzen.
(*f*) Rüchen-Komfort.
(*g*) Komfort des Gesässes.

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FUNCTIONAL ANTHROPOMETRY OF ELDERLY WOMEN

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For a small sample of elderly women means and standard deviations of body measurements relevant to problems of domestic design are presented. The data suggest that the elderly are a specialized population, in designing for whom it is especially important to apply ergonomic principles.

§ 1. Introduction

Designing for the elderly presents its own peculiar problems. There is increased incidence with age of arthritis and other crippling diseases which restrict range of joint movement. Moreover, normal healthy individuals, with advancing age, show physical changes which affect posture, stance and reach. This problem has been referred to briefly by Floyd and Roberts (1958) in relation to anatomical and physiological problems of chair and table design. The relatively few studies available show that physical fitness, as assessed by respiratory and circulatory recovery times after standard exercise, undergoes a slow but constant deterioration to the age of 70, after which age it declines more rapidly until in those over 90 performance of only light exercise usually leads to general discomfort and breathlessness and recovery takes a long period (Andersen 1959). Maximal work is reached at a lower work load than in younger people (Åstrand 1958), and at first, though there is little diminution in capacity for stationary work, when walking is also involved there is a marked lowering of efficiency (Durnin and Mikulici 1956) ; to some extent however this decline in physical work capacity is due to decreased desire for spontaneous physical activity and hence to a lower state of muscular training. Reactions become slower (Obrist 1953, Komnick 1956), e.g. the velocity of pupillary response to light stimuli diminishes, and there is a decline with age in performance of semiskilled and, less markedly, of highly skilled work (Welford 1951, Clay 1956). There tends to be increased fragility of bone and decreased elasticity of tissues (Ma and Cowdry 1950), so that minor accidents which would produce mere bruises in younger adults lead increasingly to fractures and strains ; hence activities which are normal for younger folk, such as standing on a chair to open a high window, involve an undue element of risk for the elderly—the greater because the presence of risk is not usually appreciated.

The importance of applying ergonomic principles in designing for the elderly is therefore apparent. With the present age-distribution of occupations in Britain, designing for older workers is hardly likely to be of immediate importance in industry, though it may well become more necessary if the proportion of the population which falls in the upper age groups continues to increase. However, with about one-ninth of the total population of Britain over 65, there is little doubt of the scope for designing for the elderly at home and in hospital, and it was with problems of domestic design in mind that the present pilot anthropometric study was undertaken at the request of the Ministry of Housing. Though the sample is not large it is of interest to put the results on

record, since available functional anthropometric data for the British population refer almost exclusively to the younger age groups.

§ 2. Results

Anthropometric data were required for use in the design of flats, including also various fittings, intended for occupation by old people living alone. Since a number of similar flats are already occupied at Oxford, Ash (Guildford), Reading, Cookham, and Amersham, it was thought that their residents would provide the most appropriate sample of intended users. Occupants of these flats kindly agreed to cooperate. A sample of rather more than a hundred subjects was expected. Some residents were away on holiday, however, others were out at work either full- or part-time (though by evening visits measurements were obtained from some of these) so that in the event a total sample of 88 was examined, of whom most were born in the counties where they were now living, or in nearby districts.

In Table 1 the age and sex distribution of the sample is compared with that of residents of similar flats in other parts of the country (kindly made available by Mrs. Adams, Research Officer, Ministry of Housing). By comparison the present sample is rather younger, though it includes several individuals in their nineties, the oldest being 99. This age difference is possibly due in part to the fact that nearly all the dwellings visited were of recent construction, and the age distribution of the occupants had not yet settled into the form which would later become characteristic, for many of the first inhabitants would expect to live there for a long time. There is however close correspondence between the two samples in the sex distribution. A sample

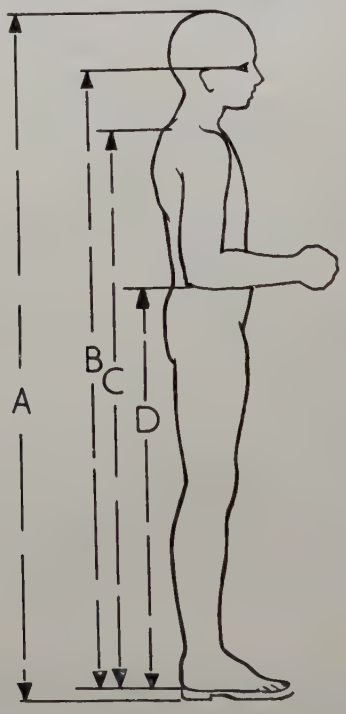

Figure 1.

Table 1. Age and sex of residents in old peoples' flats

	Under 70		70–74		75–79		80 and over		Total
	Female	Male	Female	Male	Female	Male	Female	Male	
Sample measured (Oxford, Ash, Reading, Cookham, Amersham)	23	5	33	1	12	3	10	1	78 / 10
	28		34		15		11		88
Residents at other flats (Oldham, Royton, New Forest, Cuckfield, Thingoe, Spilsby)	19	2	23	6	19	2	23	4	84 / 14
	21		29		21		27		98

Table 2. Anthropometric data for elderly women

		M	S.D.	n
	age	71·65 yrs.	7·51	78
	weight	132·68 lb.	29·74	76
A	stature with shoes	61·16 in.	2·50	77
	stature without shoes	60·06 ,,	2·45	78
B	eye height, standing	55·54 ,,	2·66	78
C	acromial height, standing	49·48 ,,	2·14	78
D	elbow height, standing	36·73 ,,	1·89	78
	heel height	1·13 ,,	0·44	77
Sitting on a 17 in. chair				
a	elbow height above seat	7·57 in.	1·21	78
b	vertex height above seat	31·27 ,,	1·43	78
c	eye height above seat	26·82 ,,	1·47	78
d	occiput height above seat	28·09 ,,	1·44	78
e	height of shoulder blades above seat	15·68 ,,	1·09	78
f	height to acromion above seat	20·67 ,,	1·23	78
g	popliteal height from floor	15·15 ,,	0·85	78
h	height to top of knee from floor	18·83 ,,	0·87	78
i	height of top of thighs above seat	4·96 ,,	0·90	78
j	distance from front of knee to sacral plane	22·04 ,,	1·36	78
k	distance from popliteal angle to sacral plane	18·46 ,,	1·14	78
l	distance from heel to sacral plane	36·76 ,,	1·78	78
m	width of thighs	14·74 ,,	1·55	78
n	bi-deltoid width	16·26 ,,	1·17	78
o	horizontal distance from back of thorax to gripped pencil, arm horizontal	28·56 ,,	1·67	78
p	horizontal distance from back of thorax to gripped pencil, arm straight, hand 11 in. above seat	25·35 ,,	1·84	78
Standing				
q	distance from abdomen to gripped pencil, arm horizontal	18·54 ,,	2·40	77
r	distance from abdomen to gripped pencil, hand on 34 in. table	13·96 ,,	2·34	77
s	maximum comfortable upward reach	71·67 ,,	3·43	78
t	maximum comfortable upward reach with 14 in. obstruction	67·04 ,,	3·89	77
u	fist carrying height at side	27·58 ,,	1·87	78
v	fist carrying height with 14 in. obstruction	32·43 ,,	2·07	77
w	radius of chalk circle, right hand, arm straight	19·29 ,,	1·55	77
	grip diameter—index finger	1·34 ,,	0·15	76
	grip diameter—middle finger	1·56 ,,	0·17	77
	grip strength	13·95 kg	4·29	76

M = mean ; S.D. = standard deviation ; n = no. in sample.

with 30–40 per cent of men had been expected, in view of age differences in the sex ratio, so that the marked preponderance of women was quite surprising. It was not due to the omission of men out at work in the daytime, but to the fact that men form only a minority of the resident population of these flats, and most of those reside with their wives in the larger two- and three-room units intended for dual occupation. In practical terms, this means that such flatlets and their fittings should be designed primarily for use by women, and it is the data for the female sample which are recorded here.

On each subject stature was first measured with shoes on. She was then asked to remove her shoes and the remaining measurements were taken ; any application of these therefore requires to be adjusted, where relevant, for heel height—lower than that for the general female population. The measurements, all made with the subject clothed, are shown diagrammatically in Figs. 1 and 2. Further details of technique of measurement are set out in the Appendix. In Table 2 are given the mean, standard deviation, and number in sample for each measurement ; a few individuals became fatigued during examination and withdrew, so that the full sample of 78 women was not available for every measurement.

§ 3. Conclusions

It is clear from the results that in designing for the elderly one is catering for a specialized population. First, in this sample the body size is smaller than in the younger female population of Britain, stature for instance being some 3–4 in. below that regarded as average for British women (63–64 in.) ; a similar trend is apparent in the older age groups of other samples, e.g. that of Norris *et al.* (1956). To some extent this difference may possibly be attributable to secular changes in size, for the present sample is drawn from an earlier generation whose stature as young adults was rather below that of the present generation. There is however the possibility of tissue shrinkage to take into account and certainly a postural factor as well, for in many the stoop of age is firmly established, causing a reduction in the average of all vertical measurements in which trunk height is involved.

Secondly, in the measurements of comfortable reach, particularly upwards, there is a source of variability which is much less important in younger samples, namely reduction of the reading due to arthritic and other limitations of joint movement, so that the observed variance is increased.

Thirdly, there is the relative weakness of muscular effort of the present sample ; the average dynamometer grip strength of preferred hand of 14 kg is markedly less than that observed with the same instrument on a sample of young adult males (37 kg). Again the low average is partly due to those subjects with arthritic hands, who could only exert a grip strength of 3 or 4 kg ; even in the unaffected individuals however, it was rarely that a subject managed to attain more than 20 kg.

The relevance of each of these peculiarities to the design, provision and manipulability of fittings for the elderly is obvious. The extent to which they are characteristic of the elderly population as a whole clearly calls for investigation on a larger sample of wider provenance.

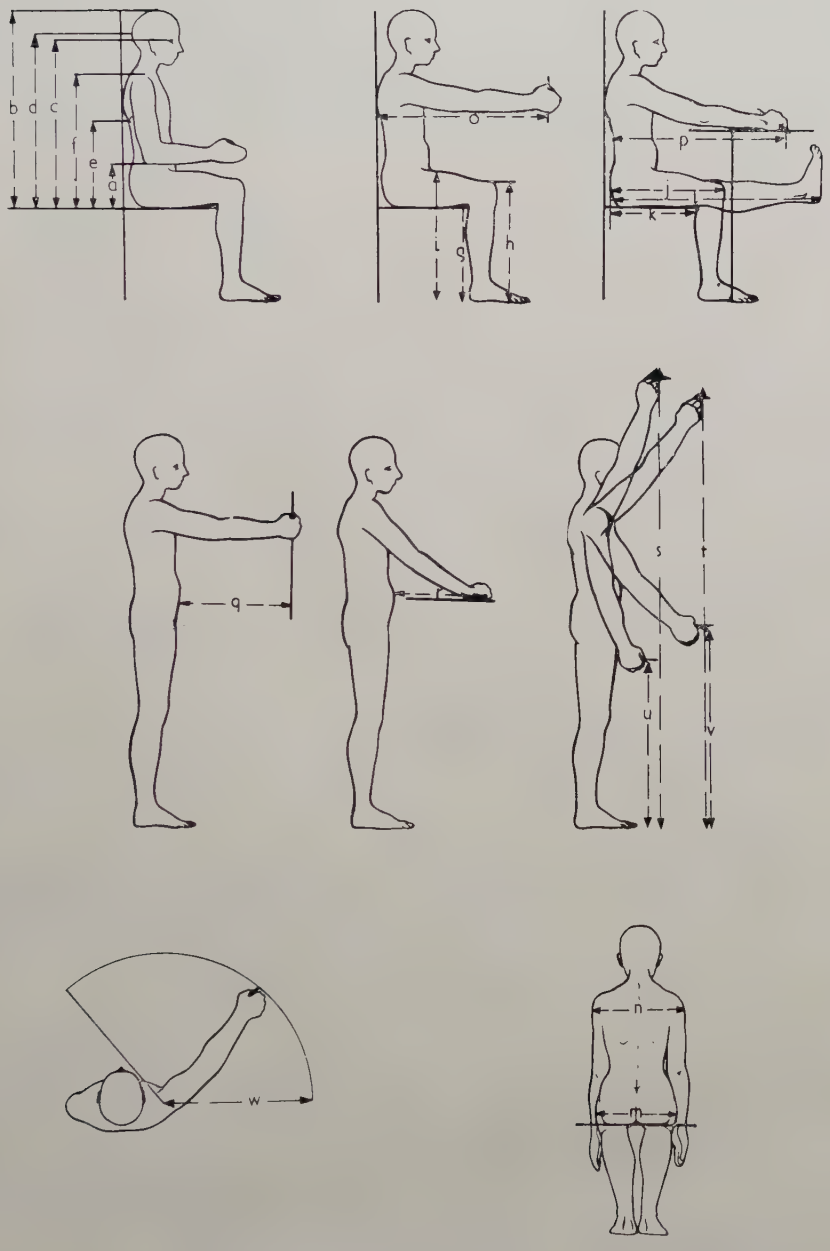

Figure 2.

Appendix

In all measurements the subject was standing or sitting normally and upright, not in a forced position, and, except in the measurements of upward reach (*s*, *t*) and radius of working area (*w*), looking horizontally in front. The seated measurements were taken with the subject sitting sufficiently far forward on a horizontal 17 in. high wooden seat as to enable her to put her foot flat on the floor without compressing the soft tissues under the lower thigh ; measurements (*g*, *h*) of popliteal and knee height are thus practically independent of the seat height.

Standing measurements (Fig. 1).

A stature : height to vertex, the topmost point in the median sagittal plane of the head ;

B eye height : to the level of the pupil, the subject looking horizontally forward ;

C acromial height : to acromion, arms hanging, shoulders level ;

D elbow height ; upper arm hanging, forearm bent to the horizontal position, measured to the plane of the inferior surface of the forearm at the elbow ;
heel height : the difference between stature shod and stature unshod.

Seated measurements (Fig. 2).

a elbow height : arm positioned as in the standing measurement ;

b vertex height : to topmost point in the median sagittal plane of the head ;

c eye height : to the level of the pupil ;

d occiput height : to the most posterior point of the head ;

e shoulderblade height : to lowermost point of shoulderblades, arms hanging ;

f acromial height : to acromion, arms hanging, shoulders level ;

g popliteal height : to the angle between the thigh and calf formed by the soft tissues, no pressure being exerted, the lower leg being vertical ;

h knee height : to the uppermost point on the patella ;

i thigh height : to the uppermost point on the thighs, wherever it occurred ;

j, *k*, *l* distances of front of knee, popliteal angle, and plantar plane of heel from the sacral plane ; horizontal distances to the vertical plane passing through the most posterior point on the sacrum ;

m thigh width : horizontally across the greater trochanters, the subject sitting with legs comfortably placed ;

n bi-deltoid width : horizontally, the arms hanging ;

o, *p* horizontal distances for gripping above (*o*) and on (*p*) a working surface 11 in. above seat (subject sitting) ; taken to the most rearward point on the back in the same horizontal plane as the hand, the subject reaching normally without twisting the trunk or stretching ;

Standing measurements

q, r horizontal distances to grip above (q) and on (r) a working surface (standing) at a height of 34 in. ; from the edge of the table, the edge of which the subject's abdomen was touching ;

s maximum upward manipulable reach : without stretching, the heels flat on the floor, measured to the mark made by a horizontal pencil held normally between the thumb and fingers ;

t maximum upward reach with obstruction : as above, but the subject toeing a line 14 in. from the vertical scale and not leaning forward (this corresponds approximately to a 17 in. obstruction at waist level) ;

u fist carrying height at side : to gripped pencil ;

v fist carrying height with obstruction : subject positioned as in (t), measured to gripped pencil ;

w radius of chalk circle : drawn on working surface, with arm straight, subject standing erect, not twisting the trunk and leaning neither forward nor sideways ; the difference from (r) is due to the difference between the line of grip and the tip of a piece of chalk held normally for drawing, and to the difference in position of the shoulder joint when the arm is swung round from the side and when it is raised horizontally forward.

grip diameter : maximum diameter when thumb tip and index (or middle) finger tip lightly touch ;

grip strength : better of two attempts, with a Salter's improved dynamometer.

On présente des données (moyens, σ) anthropométriques obtenues sur un échantillon de vieilles. Aux problèmes de dessin des appartements, des meubles etc, exclusivement pour les vieilles, qui font population spécialisée, il est très important d'appliquer des principes ergonomiques.

An einer kleinen Probe ältlicher Frauen sind anthropometrische Angaben (Mittel, σ) ermittelt worden, die sich auf Probleme der Haus- und Küchenienrichtungen etc. beziehen. Es geht aus diesen Angaben hervor, dass Altliche ein Spezialbevölkerung darstellen, so dass, wenn man für sie plant, die Anwendung ergonomischer Prinzipien besonders wichtig ist.

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DESIGN REQUIREMENTS FOR MAN GENERATED POWER

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A scheme is presented for designing man-powered devices for optimal power transfer from human operator to mechanism. This scheme is a mathematical description of human dynamics in terms of components capable of storing and releasing energy. Such a description provides a notion of the information required for the engineering design of man-machine systems and indicates a possible direction for potentially fruitful research.

The work conducted by Hill's school, culminating in Wilkie's data demonstrating the measurements and theoretical considerations relating to individual muscle fibres, can be used to predict the performance of the gross anatomy of the body, is reviewed.

Data on the efficiency of muscular work and human power output are discussed. In addition, certain data for human power generation by handwheels and pedals are presented in terms of short duration and sustained efforts.

§ 1. Introduction

Man is a gregarious tool-using animal. Within this definition lies the central problem of human work sciences: how do men function in company with other men, with machines, or with both men and machines? This paper will be concerned with a restricted phase of man's tool-using activity, namely, his ability to perform useful work in the physical sense of the word.

Useful work achieves a change, external to the energy-producing device, which is desirable according to some given criterion. Power, the time rate of doing work, is the major interest of this paper. Horsepower will be used as the standard unit since this has a certain intuitive appeal; one horsepower is defined as 550 ft lb./sec.

When the tools or machines with which man worked were rather primitive the major purpose in using a man to operate a machine was to exploit his ability to generate mechanical power in a controlled fashion. As technology advanced it became less important that the human operator be capable of generating power and more important that he function as a control element.

It is impossible to isolate completely the human operator's control function from his power-generating function since any measurements will involve some form of power-produced output. We can, however, as a practical matter, distinguish between those functions of the human operator which are *primarily* control and those functions which are *primarily* power production.

§ 2. Efficiency of Muscular Work

Although there are many maximum effort exertions in which power may be generated without regard to cost, there is utility in knowing how efficiently the human body converts its fuel into mechanical work. Such information is of direct value in establishing caloric requirements for the performance of energy-consuming tasks such as marching, industrial work, athletics, etc. (Astrand 1956, Dill 1936, Passmore 1955). A more exciting possibility is implied in the encapsulation of human operators for future space travel. Such encapsulation would require a knowledge of the heat transfer and mechanical properties of the man in this closed system. Since fuel would be at

a premium, it might not be feasible to use as many power-amplifying devices as under our usual conditions of existence. A human passenger may have to pay in services for his weight by observing, controlling perhaps by changing the vehicle's attitude and, when necessary and possible, generating power. Man's capacity to do work is controlled by his fuel, the amount of oxygen available to his muscles, and by the carbon dioxide concentration in his ambient atmosphere. The logistic economy involved in supplying food energy to the man would present a painstaking though solvable problem. An associated problem is that the man can live only in a rather restricted temperature range. Since muscular activity is the major means available for controlling body temperature, it would be necessary to consider the heat balance problems.

Muscle activity produces heat during the mechanical response (initial heat) and during the re-energizing or recovery period (recovery heat). The initial heat in a single twitch is composed of two parts: ' heat of activation ', A, and ' heat of shortening ', ax, where x is the distance of shortening.

The heat of recovery is the exothermic balance of a series of endothermic and exothermic reactions which accompany the oxidation processes by which the muscles slowly restore the chemical substance from which the muscular activity derives its energy. This recovery heat, in the presence of oxygen, is approximately equal to the total initial energy released as activation heat, shortening heat, and work. Thus, E, the energy of contraction in a single twitch is

$$E = A + ax + W,$$

and the total energy output is approximately $2E$. The efficiency of performing work is then:

$$Eff = W/2E.$$

Over short periods of time the vascular system can adjust so as to allow a greater amount of oxygen to be supplied to the hungry active muscles at the expense of other parts of the body, such as the viscera. In this way, peaks of power are achieved essentially by spreading the oxygen debt over the whole body rather than limiting it to a specific muscle complex. The limiting aerobic power a man can generate without building up an oxygen debt can be determined from the maximum rate at which he can absorb oxygen from the atmosphere. Astrand (1956) found this rate to be fairly stable and, expressing it in terms of kilograms of body weight, equal to about 67 ml O_2/kg × min for a group of elite male athletes and equal to about 59 ml O_2/kg × min for a group of male students of comparable ages. This illustrates the greater capability of the athlete's oxygen transport system, which is at least partially attributable to endurance training.

One can convert this oxygen consumption to an energy production of about 22·5 kcal/min. Since man's conversion efficiency to mechanical energy is about 20 per cent, with 25 per cent as a possible upper limit, peak aerobic horse-power is theoretically 0·4 to 0·5 h.p., depending on the size of the man. For short bursts, acting anaerobically, the man can put out a greater effort, but he must repay the oxygen debt at the end of his efforts.

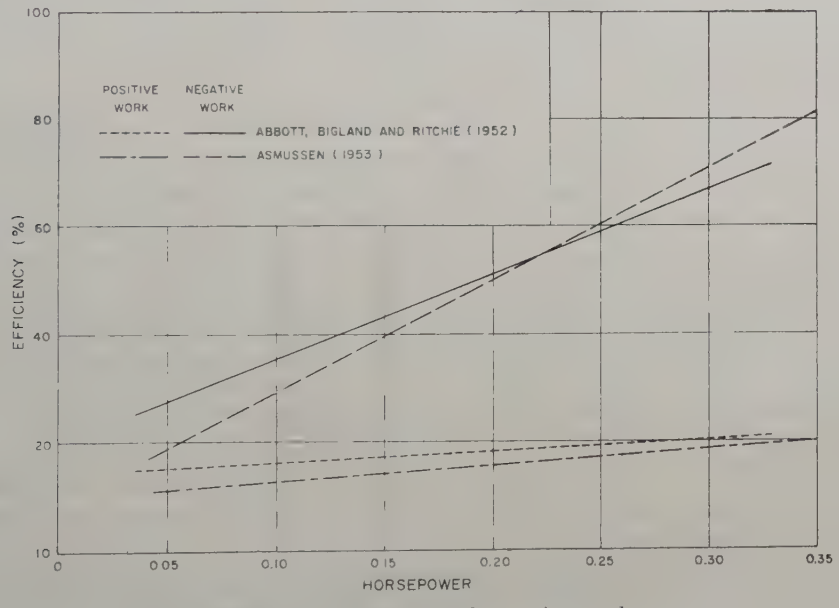
Most of the physiological factors involved in muscular efficiency are beyond the machine designer's control, but the optimal speed for efficient work may

be specified. This speed may not be practical, since rate of energy production may be as important as efficiency for a given application.

Another factor over which the machine designer has some control is the extent to which various muscle groups will be permitted to have work done on them ('negative' work) while lengthening, as compared with doing 'positive' work while shortening. It is clearly to be expected, however, that 'negative' work in which the muscles have work done on them as they lengthen, as in bicycling downhill, will cost less physiologically than the converse example of positive work in bicycling uphill.

The bulk of the experimental data on the cost of negative work were obtained from bicycle ergometer studies. Asmussen's (1953) technique was to have a subject bicycle on a treadmill which could be pitched to simulate up or downhill cycling. Abbott *et al.* (1952), on the other hand, arranged two bicycle ergometers so that one subject drove the other. Thus, the man doing negative work was not back-pedalling, but was actually interchanging muscle lengthening and shortening in his work efforts. Thus, both cyclists exerted equal forces at equal speeds.

The efficiencies as functions of horse-power for both positive and negative work are presented in the figure. These values were derived by an approximate conversion of O_2 consumption to horse-power from data on the increase of O_2 consumption above rest conditions for steady state work.



Efficiency of positive and negative work.

§ 3. Power Transfer

Consider a human power source connected to a load; i.e., some device on which work is to be done (Olson 1943). We can characterize the human power source by a force output $f_M(t)$, an internal impedance, Z_M; composed of resistance, R_M, and a reactance, X_M. Similarly, we can characterize the

load as having an impedance, $Z_L = R_L + X_L$ and $R_L = R_{UL} + R_{FR}$, where R_{FR} is the resistance in the load due to frictional efforts and R_{UL} is the resistance characterizing the useful load.

First, let $f_M(t)$, be equal to a constant F_M, and let $X_M = X_L = 0$. Under these conditions the following may be shown to be conditions for maximum useful power transfer.

(*a*) Minimize R_{FR} under all conditions.

(*b*) Consider R_M, the man's internal resistance, as a variable. Such a condition may arise as a consequence of a work scheduling such that fatigue products are minimized, or it may arise by properly choosing the man's location with regard to his machine, or by a proper choice of required human output since R_M is a function of the speed of the movements of the operator's limbs. R_M should be minimized under all of these conditions.

(*c*) Consider the useful resistive load itself, R_L, as a variable. This is, of course, the most common circumstance which we might encounter in practice. Useful power is maximized when

$$R_{UL} = R_M + R_{FR}.$$

The foregoing illustrates that it is reasonable to postulate a maximum power transfer condition for a human operator generating a steady force output. However, when attempting to match impedances one is confronted with the problem that neither F_M nor R_M are independent of one another; nor are they independent of time. The circumstances under which a man exerts a force determine the time history of this force, the time history of his internal resistance, and their mutual interdependence.

In a subsequent section, it is demonstrated that studies of running provide empirical validation of the possibility of describing the human prime mover in terms of internal resistances and useful work performed by the runner.

Consider a sinusoidal time dependency of the force which the man generates: $f_M = F_M \exp(j\omega t)$, without discussing attenuation with time. A harmonic output is a reasonable approximation to an on-off duty cycle type of operation. Defining the power-generating system as the man and a wheel which he may rotate, then a steady state operation yields a harmonic force output by the conversion of this system's output to a linear motion. Essentially the same reciprocating effect can be obtained by operating such mechanisms as a pump handle.

The useful purpose served by introducing a model for force output which has a periodic time characteristic is that we can elaborate the man's impedance, Z_M, and the load's impedance, Z_L, by including the reactance terms. Reactance elements can be thought of on an intuitive level as devices which can store and then release energy. Thus, if energy is supplied to a system in a periodic fashion it might be possible to arrange reactance elements in such a manner that a smooth energy output would result.

The optimal power transfer conditions are as follows:

(*a*) R_{FR}, the frictional resistance, should be as small as possible.

(*b*) As the variable, R_M should be as small as possible. If, in addition. X_M and X_L can be controlled, then the maximum occurs for $X_M = -X_L$.

(*c*) If the useful resistive load, R_{UL}, is a variable under control, then maximum power transfer conditions become:

$$R_{UL} = \{(R_M + R_{FR})^2 + (X_M + X_L)^2\}^{1/2}$$

where, as before, R_{FR} is to be made as small as possible.

If one or both reactances are adjustable, then $X_M = -X_L$ is another maximizing condition.

As with the constant force output condition, there is the problem of parameters in the power transfer expression which are dependent both on the conditions of exertion and on time. The man's mechanical reactance, X_M, however, is somewhat less dependent on the foregoing factors than is the resistive term R_M. This follows from the definition of X_M in terms of system components:

For rotational motion

$$X_{M\phi} = j\left(\omega I_M - \frac{1}{\omega C_{M\phi}}\right).$$

For rectilinear motion

$$X_{M\rho} = j\left(\omega M_M - \frac{1}{\omega C_{M\rho}}\right).$$

I_M is the moment of inertia, and M_M is the mass for that portion of the operator's anatomy which is involved in generating power. Clearly this parameter, though dependent on the technique selected for generating power, is relatively insensitive to time effects. The compliance terms, $C_{M\phi}$ for rotational motion, and $C_{M\rho}$ for rectilinear motion may change with both the operator's position and with time. This is because the resilience or springiness of the anatomy is a function of muscle tone which is presumably governed by such time-dependent effects as fatigue.

The foregoing development has provided a rudimentary theory for the synthesis of human power-generating devices for maximal power transmission to a useful load. The types of information needed about the human operator for the design, from the foregoing basis, of a man-operated power-generating device can be outlined. Primarily, measures of the human operator's forces, compliances, resistances, masses and inertias as they exist in various postures and as they vary with time are required. Drillis (1959), over the last three decades, has made extensive measurements of limb position as a function of time from which he has deduced masses and inertias from the equations of motion while the subject performed work activities.

§ 4. Characteristics of Striated Muscle

Although human power generation could be studied on a gross level without any detailed notions of internal functioning, the required description of human dynamics in terms of components capable of storing or releasing energy implies that a detailed notion of the functioning of man's muscles might shed some light on the validity or range of applicability of such a description.

The thesis that gross muscular behaviour could be predicted in terms of the behaviour of isolated striated muscles was the guiding principle for a series of inspired experiments conducted over the last four decades by A. V. Hill

and his colleagues. Originally, the central concept in this work was that striated muscle tissue, without regard to its biological origin, had a ' visco-elastic ' property and could be described as a mechanical system. This early lack of emphasis on the physical chemistry of muscles proved to be the undoing of this theory when it was used to estimate the efficiency of muscular activity.

In later work, which was influenced by Fenn (1930, 1931, 1938), Hill (1938, 1950) became convinced that the ' visco-elastic ' model accounted for, at best, a minor part of the description of muscular behaviour. He then introduced concepts which recognized the physico-chemical as well as the mechanical nature of muscles.

A finding from these later experiments was that an active muscle appears to be a two-component system consisting of an undamped, purely elastic element in series with a contractile element.

In an elegant series of experiments on maximal elbow flexion, Wilkie demonstrated that Hill's theory as derived for isolated muscles could be shown to apply to gross muscular behaviour. In addition he measured the muscles' compliance. Evidence from excised muscles favours the hypothesis that the hyperbolic force–velocity curve is characteristic of the muscle itself rather than the result of innervation scheduling.

In plots of the velocity of the hand *v.* time in the maximum effort elbow flexion experiments, Wilkie noted an oscillating tendency in the response which varied with the force load on the arm. He related this to Hill's postulated contractile plus elastic element model for a muscle. Seeking to magnify the effect, he incorporated a series compliance in the cable on which the man exerted force. He was then able to indicate experimentally that the oscillation was, indeed, due to internal series compliance and was able also to measure this compliance (Wilkie 1949, 1950).

§ 5. Power Generation—Running

A man may do work on his own body by propelling it forward, thus imparting either kinetic energy or both kinetic and potential energy to his body, thus illustrating some of the characteristics of the human prime mover.

In an application of Hill's early theory of internal viscosity effects in muscular exertion to an experimental study of sprint running, Furusawa *et al.* (1927) proceeded as follows: Let M be the mass of a runner who can exert a maximum force, F, in propelling himself forward horizontally on a level track. Assume

$$F = fMg,$$

where g is the acceleration of gravity and f is a dimensionless characteristic of the runner's build, strength, fitness, etc., which has the following range: $0{\cdot}5 \leqslant f \leqslant 1$. Internal losses and fatigue put an eventual limit on the velocity which the runner can attain, but Hill assumed that his hypothesized viscous drag effect acted first. This viscous resistance may be assumed proportional to muscle size and roughly proportional to body weight as follows:

$$\text{viscous losses} = Mv/a,$$

where M is the runner's mass, v is the horizontal forward velocity, and a is

a constant. The differential equation of a runner, up to the stage where fatigue begins, is therefore:

$$M\frac{d^2y}{dt^2}=fMg-\frac{M}{a}\frac{dy}{dt}.$$

The solution is

$$y=fga[f=a\{1-\exp(-t/a)\}],$$

and

$$v=fga\{1-\exp(-t/a)\};$$

where y is the distance run, and t is the time measured from the moment that the muscles have become innervated.

A series of experiments was performed on sprinters and the results show a remarkably close fit to the solution of the foregoing equation so that:

$$v=v_0\{1-\exp(t/a)\},$$

where $v_0=fga$ is the terminal velocity before the onset of fatigue. This equation form is commonly found where an energy storage device is in the process of discharging its energy subject to resistive losses.

Best and Partridge (1928) expanded this type of study by loading their runners with a resistance, R, by means of a cord attached to the waist which unwound from a friction-loaded capstan. They found that the dynamic equation of running was modified, as expected:

$$M\frac{d^2y}{dt^2}=fMg-R-\frac{M}{a}\frac{dy}{dt}.$$

The early viscous friction model of Hill, although not tenable on a muscle fibre level, provides an adequate average description for gross muscle power data such as running. This is despite the fact that Fenn (1930, 1931) made a detailed analysis of running to determine where and how the energy losses actually occurred and demonstrated that viscous friction losses were negligible.

In an impedance-matching model, the ability of the muscle to convert kinetic energy to potential energy and then to release this energy at an appropriate time is of importance. A muscle which takes up the impact, Ft, of a moving limb stretches and may be thought to have acquired potential energy. The stretched muscle, however, must maintain continuous contractions in order to retain this potential energy. Thus, the muscle is continuously losing and redeveloping energy. A muscle may be thought of as ' charging storage ' for stored energy at a rate determined by the balance of the dissipative and regenerative actions. In the movements in running, the maintenance cost or ' storage charge ' is less than the cost of redeveloping the tension in the muscles (Fenn 1930 1945, Wilkie 1954). In other movements, this may not be the case. In any event, a simplified spring constant picture of muscle energy storage in isometric contractions is, at best, a rough approximation to a complex process. Where it is possible to measure equivalent attenuation factors and effective spring constants, the concept is useful for gross calculations.

§ 6. Useful Human Power Output—Cranking and Pedalling

Although such data as do exist for human cranking pedalling do not shed light on the feasibility of achieving maximum power transfer, there are regularities in human power output which are of interest (Krendel 1959).

Thus in power generation by cranking where the subject was cranking as fast as possible in a sprint effort, the horse-power generated over intervals up to 300 sec depends on time in the following manner:

$$\text{h.p.} = C \exp(m/t)$$

where C and m are parameters. If, however, the subject is pacing his effort the power generated for up to 1000 sec is of the form:

$$\text{h.p.} = Kt^{-k}.$$

For long periods of power generation the sprint and the self paced outputs become equal asymptotically.

Data on power generated pedalling, cranking and pedalling and cranking together have been obtained by Ursinus for an unusually well-trained subject. For this person the power generated in the time interval from 20 sec to 120 sec was as follows, where t is in seconds:

for arms and legs	$\text{h.p.} = 4{\cdot}4t^{-.40}$
for legs only	$\text{h.p.} = 2{\cdot}8t^{-.40}$
for arms only	$\text{h.p.} = 1{\cdot}5t^{-.40}$

The data on the power output of skilled subjects presumably indicate that they do not emit a wasteful burst of energy early in the course of their activity and this incurs a rapidly increasing and fatiguing oxygen debt. Instead they appear to work either aerobically or at such a rate that the oxygen debt rises slowly until finally the efforts must stop. In the examples shown the maximum power is consistent with the 0·4 to 0·5 h.p. value mentioned in an earlier section.

§ 7. Conclusions

In the foregoing, the work conducted by Hill's school culminating in Wilkie's data has demonstrated that measurements and theoretical considerations related to the microstructure of the human musculature, i.e., the individual muscle fibres, can be used to predict the performance of the gross anatomy of the body. Evidence that the individual muscle possesses a measureable compliance was introduced by Wilkie, and mass and inertia were measured in a living subject by Drillis. These facts, with their implications that the impedance-matching concepts are realizable, are the basis of suggestion for future research.

Such research would require the measurement in the intact living organism of such dynamic parameters of human behaviour as compliance and mass in simple power-production tasks to extend the pioneering work. The attempt could then be made to design, construct, and then to test simple mechanical devices designed from optimal power transfer consideration. The positive results of a successful investigation will yield both obvious practical advantages, as well as the more fundamental benefits which will be derived from knowing more about the dynamics of human mechanical activity.

On présente un plan systématique pour l'étude du transfert optimum de l'énergie musculaire humaine à des engins mécaniques. Ce plan est une description mathématique de la dynamique humaine en fonction d'engins capables d'emmagasiner et de liberer l'énergie. Une telle description fournit une notion des renseignements requis pour l'étude des systèmes d'engins actionnes par l'énergie musculaire et indique un champs possible de recherches fructueuses.

On revise les travaux conduits par Hill et ses collègues qui ont abouti aux renseignements fournis par Wilkie sur la démonstration des mesures et sur des considérations théoriques se

rapportant à des fibres musculaires individuelles et qui peuvent être utilisés à prédire la performance de l'anatomie du corps.

On examine également des informations sur l'efficience du travail musculaire et sur la puissance fournie. En outre, on présente certains renseignements sur la production d'énergie au moyen de mécanismes à manivelles et à pédales pour des efforts de courte durée et pour des efforts soutenus.

Eine schematische Skizze zeigt eine hoechstmoegliche Umformung der Koerperfunktionen der menschlichen Taetigkeiten durch einen Mechanismus. Diese Skizze ist eine mathematische Beschreibung von menschlicher Dynamik in Einzeldarstellung von Komponenten, welche die Energie der Lage und die Energie der Bewegung tragen. Solch eine Darstellung gibt einen Begriff von den Daten, die fuer die technische Auswertung des Mensch-Maschine Systems benoetigt werden und zeigt eine moegliche Richtung fuer eine positive Entwicklung.

Die Arbeit, die von der Hill Schule geleitet wird und in den Wilkies Angaben gipfelt wird ueberprueft. Sie legt die Messungen und theoretischen Betrachtungen dar, die in Bezug auf individuelle Muskelfasern und auf die Funktionen der allgemeinen Anatomie des menschlichen koerpers angewandt werden koennen.

Angaben ueber die Muskelkraft und menschliche Leistung werden besprochen. Weiterhin werden Darstellungen gebracht ueber die Weiterleitung menschlicher Leistungsfaehigkeit durch Handkurbelrad und Fusspedale.

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EXPERIMENTAL INVESTIGATIONS OF CAUTIONARY SIGNAL PRESENTATIONS

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Four experiments were performed to investigate optimum methods for presenting cautionary-warning information. In each experiment multiple compensatory tracking constituted a primary task, while response to various cautionary-warning signals constituted a collateral task. Experiment I investigated the effects of a centrally located master signal on response to peripherally located cautionary indicators. Experiments II and III compared the effectiveness of various types of visual, auditory and combined visual-auditory master cautionary-warning signals under various levels of task complexity. In Experiment IV, the design of lensed, legend cautionary-warning indicators was investigated. The major results of the four experiments indicated that when multiple cautionary-warning signals are presented peripherally : (1) the use of a master signal reduces response time and the number of signals missed, (2) auditory master signals are superior to visual, (3) the use of a combined visual-auditory master produces the fewest missed signals, (4) a two-tone auditory master is superior to a one-tone, (5) for illuminated legend signals, a dark legend on an illuminated background is superior to an illuminated legend on a dark background, and (6) for the former type a letter height of $\frac{1}{4}$ in. is superior to one of $\frac{1}{8}$ in. (height to width ratio 5 : 3) but is not significantly better than one of $\frac{3}{8}$ in.

Considerable effort has been focused upon the determination and implementation of improved methods for presenting warning and cautionary information to aeroplane pilots. The need for light indicators, especially, in this regard is not often disputed. However, questions are frequently raised concerning whether too many functional situations are already being handled by the visual modality, thus ' watering down ' the impact of light indicators ; whether a display involving cueing through both the visual and another supplementary modality would be better (the auditory being the most frequently suggested) ; whether the form of presentation should be primarily of the legend type (if the visual sense is involved) and, if so, what specific type of legend presentation is best ; and so on.

The present paper describes a series of four experiments concerned with the optimum presentation of cautionary-warning information.

Experiment I :

Effects of a Master Caution Indicator on Responses to Peripheral Indicators

With the increase in the number of caution and warning indicators in current aircraft, it has become necessary to locate some cautionary light indicators outside of the major forward panel area. This has led to the proposal that a master caution indicator, which would light up when any one or more peripherally located signals were illuminated, should be located centrally on the forward aircraft panel. Logically, it appears that such an indicator would serve a useful purpose. Under certain conditions the visual demands on the pilot are too great for him to pay any but cursory attention to peripheral indicator devices. Under these conditions the infrequency of scanning for the

presence or absence of a cautionary indication might result in serious consequences. On the other hand, incorporation of an additional light indicator into the central or near-central, ' premium ' panel area (defined by the so-called 30° cone of vision) seems unwise unless it can be shown that the master indicator truly enhances the overall effectiveness of the cautionary system. In this first study, an investigation was made into the effects of the presence of a master visual caution indicator on the responses to peripherally located cautionary light indicators.

Apparatus and Procedure

The apparatus which constituted the basic experimental equipment was a flexible electronic light indicator simulator (FELIS), designed and constructed by Applied Psychological Services specifically for research on aircraft caution and warning signals. The FELIS apparatus consists of a master control console (the experimenter's console) and a flight task simulator (the subject's console). The former is a semi-automatic control source applicable to control requirements calling for multiple circuit switching in a sequentially timed programme. Stimulus brightness, flash rate, activation of one of three peripheral caution-light panels, activation of individual caution lights within each panel, as well as the push-button control for extinguishing any of the lights are controlled from this console. Additional console controls permit the presentation of specific light-signal patterns.

The flight task simulator is a device which incorporates five tracking displays and three panels of light indicators. The tracking displays consist of five milliammeters, three on the forward instrument panel and one on each side panel of the simulator. Excursions of the milliammeters' pointers occur in accordance with the programme set into the master control console. Pointer excursions can be produced in one, all, or any combination of the meters at any instant ; hence, the ' load ' on the subject can be varied. Since the pointers are driven in a preplanned manner and are automatically timed and sequenced, precise experimental control over the presentation of stimuli for tracking can be maintained. Below each milliammeter is a rotary control knob for use by the subject in keeping the needle centred.

In the first study, a master caution light was centrally located on the subject's console, directly forward and 15° down from the horizontal visual axis. Two peripheral signal banks, each containing nine caution-light indicators, were mounted on the right-hand side of the simulator, peripheral I being forward and near the lower right portion of the forward panel area and peripheral II being farther back at the side of the console. Specifically, peripheral I was located 33° to the right of the subject's sagittal axis, 50° down from the horizontal visual axis, and 24 in. from his eyes ; peripheral II was 95° right, 69° down, and 23 in. from the eyes. Below each light panel were nine push buttons. Each push button was associated with a given light which it extinguished when pressed. When a light was illuminated in accordance with the programme set into the master control console, a centisecond timer on the control console was also started automatically. Extinguishing the light by the push button stopped the timer, thus providing a means for measuring response time to the onset of the light.

Two levels of surround brightness were used to approximate day and night flight conditions. In the ' night ' condition, diffused, flood illumination was provided by two side-mounted Grimes B-4745-3 rheostatically controlled fixtures and two ceiling-mounted rheostatically controlled Soderberg fixtures. Both the Grimes and Soderberg fixtures were fitted with aviation red filters. The surface illumination of the milliammeter dial faces and push buttons was maintained at a brightness of 0·06 ft lamberts, a level above minimal dial reading requirements (Spragg and Rock, 1948). For the day condition a bank of four 300 W reflector flood lamps yielded a 300 ft lambert ' day '-surround brightness value for the panel-mounted indicator devices.

The intensity levels of the caution lights were selected on the basis of contrast with the surrounds. Day and night intensities were fixed at a contrast level which would be slightly above the difference threshold but which would, additionally, assure discrimination within, on average, about two-thirds of the maximum time (4·75 sec) allotted to each presentation. The brightness values used were obtained by averaging the judgments of four observers experienced in visual research. The master caution light was maintained at a brightness identical to that of the peripheral lights, and when the experimental design called for the master, it automatically lit up simultaneously with the peripheral light. Prior to tests with the simulated night condition, each subject was dark adapted for 15 min with Naval Air Polaroid Dark Adaptor Goggles. Light adaptation of 5 min was given prior to tests under the simulated day conditions.

Seven male university students, ranging in age from 18 to 21 years, and two male staff personnel of Applied Psychological Services were used as subjects. All were fitted with an H-4 crash helmet and a 58-H-4 liner with earphones mounted. Thus, the visual restrictions, if any, as well as the head movement impediments imposed by this helmet, were incorporated into the experiment task. Seating adjustment was made for each subject such that his eye level was about 3 in. above the upper edge of the main panel. The distance from the subject's eyes to top-centre of the forward panel was 28 in. Line of sight distances to all other displays and control surfaces were between 20 and 28 in. All critical panel areas were perpendicular to the line of vision. Side panel surfaces sloped downward towards the subject at 30° to the horizontal, and peripheral stimulus lens surfaces were tilted 10° away from the perpendicular to the visual axis in order to minimize glare during the day surround-brightness condition.

Instructions to the subject led him to believe that his primary task was that of continuous compensatory tracking of the pointer excursions of two of the forward panel-mounted milliammeters. This activity constituted the simulated ' flight task '. His ' secondary ' task was that of extinguishing any of the peripheral lights as soon as they went on.

Each subject completed two testing sessions of approximately two hours each. Each session consisted of 8 runs of 5 min each. Twenty-one caution-signal presentations were incorporated into each run. Immediately following each run was a rest interval, during which the subject was told his tracking proficiency score and casual but pre-planned comments exchanged. These comments were designed to support and intensify the subject's motivation.

A two-minute practice run preceded the first experimental run.

A factorial design was used as follows :

1. Day—Peripheral I—Master ' off '
2. Day—Peripheral II—Master ' on '
3. Day—Peripheral I—Master ' on '
4. Day—Peripheral II—Master ' off '
5. Night—Peripheral II—Master ' on '
6. Night—Peripheral I—Master ' off '
7. Night—Peripheral II—Master ' off '
8. Night—Peripheral I—Master ' on '

A session consisted of either all day surround-brightness conditions (1–4) or all night surround-brightness conditions (5–8). Alternate subjects began the experiment with the day and night conditions. Within the groups of subjects thus formed both the peripheral I and II and the master ' on ' and ' off ' presentations were counterbalanced to control practice effects. The cautionary signals were counterbalanced between runs as to sequence of presentation and equalized between runs as to the number presented. Time between presentations was randomly varied from 18 to 96 sec throughout all runs.

Each of the pointers of the two meters on which the flight task was given was made to deviate an equal number of times and a random sequence of deviation was followed in each subsequent run. The subject's eye fixation at the instant before the presentation of a caution signal was controlled by causing one of the meters to deviate ; the order was varied so as not to introduce bias. Five instances were included in each experimental run in which the meter fluctuation was omitted before the presentation of a caution-signal.

Results

Two types of data were obtained : response times to the onset of the caution-signal indicators and number of caution indicators missed or not reacted to within 4·75 sec.

Table 1. Median response times (in seconds) for eight experimental conditions (Experiment I)

	Median
Day surround-conditions	
Peripheral I, Master Off	2·51
Peripheral I, Master On	2·63
Peripheral II, Master On	3·11
Peripheral II, Master Off	4·01
Night surround-conditions	
Peripheral I, Master Off	2·89
Peripheral I, Master On	2·49
Peripheral II, Master On	2·99
Peripheral II, Master Off	3·82

Grand medians for the six experimental variables

Variable	Grand Median
Peripheral I	2·63
Peripheral II	3·48
Master On	2·81
Master Off	3·31
Simulated day	3·07
Simulated night	3·05

The raw data included 21 caution-signal presentations for each subject under each of the 8 conditions. Accordingly, the data included 1512 caution-light presentations in all. A response time of 5 sec was assigned in all cases where a response was not made within 4·75 sec. The assigning of a value as low as 5 sec makes it reasonable to assume that calculated differences of response time under the various conditions would tend to be conservative estimates of the real differences involved.

The response times are presented in Table 1, and the results of an analysis of variance performed on these data are shown in Table 2. Since none of the

Table 2. Analysis of variance of response times (Experiment I)

Source	Degrees of freedom	Mean square	F	P<	F ratio divisor
Master On-Off (O)	1	45,753·1	9·42	0·05	Ss × O
Peripheral I–II (P)	1	130,305·1	32·54	0·01	Ss × P
Day-Night (D)	1	70·0	<1·00		Ss × D
Subjects (Ss)	8	29,320·9	20·86	0·01	Combined Residual
O × P	1	23,725·7	16·88	0·01	,, ,,
O × D	1	2,415·1	1·72		,, ,,
P × D	1	3,458·3	2·46		,, ,,
Ss × P	8	4,004·3	2·85	0·05	,, ,,
Ss × O	8	4,885·0	3·45	0·01	,, ,,
Ss × D	8	4,939·8	3·51	0·01	,, ,,
O × P × D	1	3,799·0	4·85		Residual
Ss × O × D	8	1,422·3	1·81		,,
Ss × P × D	8	979·4	1·25		,,
Ss × O × P	8	2,139·1	2·73		,,
Residual	8	783·8			
Combined Residual	33	1,405·9			
Total	71				

four higher order interactions was significant, they were all grouped into one residual with 33 degrees of freedom. Taken against this residual, all simple subjects-by-main-effects interactions were significant. As is usually the case, subjects differed significantly from each other. Response time to signals did not differ as a function of brightness of surround when the signal-to-surround contrasts were about equal.

The only significant simple main effects interaction (taken against combined residual) was that between the master light and peripheral position conditions (O × P). The interaction summary is as follows :

	Grand Median Response Time
Peripheral I—Master light ' on '	2·56 sec
Peripheral I—Master light ' off '	2·70 sec
Peripheral II—Master light ' on '	3·05 sec
Peripheral II—Master light ' off '	3·92 sec

For peripheral I, master ' on ' and ' off ' differ by 0·14 sec ; for peripheral II, by 0·87 sec, an increased difference of 0·73 sec. An identical change necessarily exists in a comparison of peripheral I and II for the two master-light conditions. The least change in the difference between the two conditions of either variable that would have been significant at the 0·01 level, is 0·48 sec. Thus, the difference between speed of response to the near peripheral signal when the master

light is on, at the one extreme, and that to the more peripheral signal when the master light is off, at the other, is greater than would be expected by a simple summative combination of conditions.

Statistical evaluation of the ' miss ' data was accomplished through the use of t tests. Table 3 presents these results. All differences except that

Table 3. Significances of differences between misses by conditions (Experiment I)

Condition*	Mean difference	Standard error	t (d.f.=8)	P< † (t test)
Peripheral II *v.* Peripheral I	10·8	3·03	3·56	0·01
Master Off *v.* Master On	20·1	3·83	5·26	0·001
Day *v.* Night	2·3	1·35	1·73	—
Master Off *v.* On (Peripheral I)	6·0	1·30	4·62	0·01
Master Off *v.* On (Peripheral II)	15·2	3·29	4·63	0·01
Peripheral II *v.* I (Master On)	1·3	0·50	2·66	0·05
Peripheral II *v.* I (Master Off)	10·6	3·16	3·34	0·05
Master Off, Peripheral I *v.* Master On, Peripheral II	4·7	1·40	3·34	0·05

* The condition with the greater frequency of misses is listed first in all cases.
† Two-tailed test.

occurring as a result of the difference between the day and night surround-brightnesses were significant. It is of interest to note that the master ' off ', peripheral I condition resulted in a significantly greater number of misses than did the master ' on ', peripheral II condition.

Percentage of misses with the master indicator on was 3·4 as compared to 27·4 without the master. This ratio of roughly an eight-to-one increase in the number of ' misses ' from presence to absence of the master indicator held for each of the individual peripheral positions as well, although the total number of ' misses ' with peripheral II was roughly twice the number obtained with peripheral I. The actual percentages were, for peripheral II, 5·0 per cent with, and 38·6 per cent without the master ; and for peripheral I, 1·9 per cent with, and 16·1 per cent without the master indicator.

Experiment II :

A Comparison of Visual, Auditory, and Visual-Auditory Master Signals as Cautionary Indicators

An extensive search of the literature revealed numerous studies concerned with the problem of single-channel cautionary stimulus presentation, but only one which was concerned with direct comparison in an identical setting of several sense channels. This study (Spencer 1953 ; as reviewed by Burrows and Ford 1956), the report of which was not available to the present authors, compared three sounds—cuckoo call, variable-step oscillator, and trumpet notes—with a central visual warning system consisting of two flashing lights on the cockpit. According to the reviewers, ' auditory warnings had rather shorter reaction times than did the flashing lights, although not significantly so overall '. What this statement means is not exactly clear. Apparently the differences between the auditory and visual presentations were not very great.

It should not be surprising to find that an auditory signal is superior to a visual for those situations in which attention is not constantly focused on the

visual indicator. The more complex the total visual array, moreover, the more pronounced might such a difference be expected to be. The question of whether there would be anything further to gain from a combined auditory and visual warning-signal presentation is, however, not so evident to reason alone. Accordingly, the purpose of the second study was to investigate, in the simulated flight situation, the relative values as attention arresting stimuli of a visual master, and auditory master, and a combination of the two.

Apparatus and Procedure

The FELIS apparatus was modified to incorporate an audio-signal generator specially designed and constructed for this study by Applied Psychological Services.

The choice of the master auditory stimulus to be used in the study was made on the assumption that it would be best to simulate a signal that can be generated by an aural warning device already in existence and specifically designed for military aircraft. The signal chosen for simulation was an intermittent (8 per sec, 25 per cent duty cycle), 1800 c.p.s. complex tone (Meyer and Martin 1953).

The questions of loudness and of loudness contrast ratio for the master auditory signal were approached through a comparison method paralleling that suggested by Tonndorf (1951). The background audio input was jet aircraft noise, fixed at an intensity of 83 dB within the subject's headset, a level roughly equivalent to that found in the cockpit of jet aircraft (Burrows and Ford 1956, Houston and Walker 1949, Tonndorf 1951). Four judges, experienced in perceptual investigation, adjusted the master auditory signal until it and the background input sounded equally loud. The subjective zero-loudness-difference reference was obtained by averaging six such judgments for each of the four observers. The intensity value of the master auditory signal so determined was 73 dB. For the experimental work proper, the master auditory signal was maintained at an intensity of level of 83 dB. The four judges determined that at this level little difficulty would be experienced by subjects in discriminating the onset of the master auditory signal against the background of jet noise.

Standardized ' ability to interpret reading material ' essay passages (Iowa Tests of Educational Development 1952) were tape recorded and used as a collateral auditory task. The subject was required to attend to this material and to answer questions based on it at the end of each experimental run. The three source channels (master auditory signal, prose material, and jet aircraft noise) were ' mixed ' as required during the experimental runs and applied simultaneously to both earpieces of a standard H-4 crash helmet.

Visual stimuli, both master and peripheral, were presented at brightness levels based on the criterion of ' minimum but effective brightness contrast ', as in Experiment I. The master visual indicator was located 28 in. from the subject's eyes 15° down from the horizontal visual axis. Only one peripheral indicator bank was used, positioned 20° to the right of the subject's sagittal axis, 46° down from the horizontal visual axis, 24 in. distant from the eyes, and tilted 20° away from the perpendicular to the visual axis. Four indicator lamps arranged as a square on this bank were employed as stimuli. A bank of four push buttons, one corresponding to each light and in the same relative

positions, was situated directly forward, down 50° and angled so as to be convenient to the subject. Since an individual indicator could be extinguished only by its own control, the subject needed to identify the particular peripheral indicator involved, and could not simply react to the master signal alone.

A simulated night surround-illumination, produced in the same manner as outlined for Experiment I was maintained throughout the experiment. There was, however, additional surround-illumination provided by six Dialight fixtures, three of these being mounted as a vertical centre column on the bank containing the peripheral visual indicators and the remaining three correspondingly positioned to the left of the subject. All six were red and were maintained at a brightness level of 0·17 ft lamberts. The purpose of these lamps was to simulate the other sources of red illumination customarily found on the side consoles and forward panel of military aircraft.

The primary tasks as perceived by the subject were those of compensatory tracking of the pointer excursions of the three forward panel-mounted milliammeters and attending to the prose passage heard against the jet noise. The tracking task was accomplished as outlined in Experiment I. In the verbal task, the subject was required to answer, immediately following each run, ten multiple-choice questions based on the prose passage which had been presented. The verbal task proficiency score thus obtained was combined with the subject's score on the tracking task, yielding a ' flight task ' proficiency rating used to motivate him between runs. Performance of these ' primary ' tasks was required under the following four conditions of signal presentation : (1) peripheral light indicators alone, (2) peripheral indicators plus the visual master, (3) peripheral light indicators plus auditory master, and (4) peripheral light indicators plus both auditory and visual masters.

The experimental session was divided into six runs of 12 min each. Each run was further divided into halves (blocks) for purposes of counterbalancing sequential effects. Three blocks were run under each of the four conditions of signal presentation, the order of presentation of the blocks to different subjects being counterbalanced. Subjects were told before each run which condition would prevail during each block. A block contained eight signal presentations, and the time between presentations was varied randomly from 18 to 96 sec throughout all runs. Since three blocks were run under each of the four experimental conditions, each signal condition was presented 24 times to every subject. Since four peripheral light indicators were used, each indicator was randomly lighted twice during a block. In the tracking-task, meter fluctuations were presented randomly except for the requirement that task difficulty should be equal for all experimental conditions.

The subjects were ten male university students ranging in age from 18 to 25 years. All were fitted with an H-4 crash helmet, with 58-H-4 liner and H-3/ARR-3 earphones. They were night adapted for a 15 min period with Naval Air Polaroid Dark Adaptor Goggles prior to experimental runs.

The first run followed immediately after a subject's orientation and practice period. The experiment was administered during a single session of two and a half to three hours. In order to counteract fatigue, a 10 min break was allowed between runs, except at the ' half-way ' point where a 15–20 min break was given.

Results

A ' miss ' was counted if a response did not occur to a light signal within 5·5 sec. Within each group of 24 light-signal presentations under a given condition, the first and second misses were assigned a value of 5·5 sec each, the third was assigned a value of 5·75 sec, and any beyond the third, 6·25 sec. Any bias introduced by this procedure should tend to minimize significant differences. In any event, it was clear that the more critical variables in this regard (the three ' master ' conditions) could be affected very little by this procedure, since less than 1 per cent of their trials resulted in misses. The ' miss ' data were, however, also treated separately as a second criterion measure, since an important qualitative difference was presumed to separate them from those data for which actual response times were recorded.

In all, a total of 960 response times (including the arbitrary values assigned to the ' miss ' data) were recorded. The mean response time for each subject under each condition was determined, and the 40 means thus obtained were subjected to an analysis of variance shown in Table 4. The results of t tests

Table 4. Analysis of variance of response times (Experiment II)

Source	Degrees of freedom	Mean square	F	P<
Treatments (T)	3	102,830·9	48·54	0·001
Subjects (S)	9	12,335·2	5·82	0·001
T×S	27	2,118·4		
Total	39			

performed subsequently to the variance analysis are presented in Table 5, from which it may be seen that the mean response time with the auditory master was about half a second shorter than with the visual master. The results also substantiate the finding of Experiment I, that the combined master-peripheral signal presentation is superior to the presentation of the peripheral signals alone.

Table 5. t tests among condition means (Experiment II)

Comparison*	Mean difference	t	d.f.	P<
Auditory (2·22) *v.* Visual (2·70)	0·48 sec	5·46	9	0·001
Visual+Auditory (2·39) *v.* Visual (2·70)	0·31 ,,	1·75	9	—
Auditory (2·22) *v.* Visual+Auditory (2·39)	0·17 ,,	1·32	9	—
Visual (2·70) *v.* Peripheral (4·42)	1·72 ,,	7·20	9	0·001
Visual+Auditory (2·39) *v.* Peripheral (4·42)	2·03 ,,	7·31	9	0·001
Auditory (2·22) *v.* Peripheral (4·42)	2·20 ,,	8·70	9	0·001

* The numbers in parentheses are the mean response times in seconds for the respective conditions.

Investigation of the individual data revealed that the relatively long mean response time of 2·39 sec for the combined visual-auditory master condition was a direct result of the atypically long response times of one subject. If he is eliminated for this condition, the mean response time is 2·20 sec. This value is not significantly different from the mean for the auditory master alone, but is significantly shorter than the mean for the visual master alone. Why this subject should have such long response times under the dual master condition could not be determined. Thus, the question of whether the combined presentation added anything remains partially open : the combined presentation may

or may not have been superior to the visual master alone, at least with respect to the response-time criterion. The data clearly indicate, however, that little improvement over the auditory alone accrued from the use of the combined master.

Table 6. Number and percentage of ' misses ' for the four treatments (Experiment II)

	Total number of ' misses '	Per cent of total responses
Peripheral only	114	47·5
Visual master	2	0·8
Auditory master	3	1·3
Visual and auditory master	0	0·0

The ' miss ' data are presented in Table 6, which shows that all three ' master ' conditions resulted in very substantially (and significantly) fewer ' misses ' than the peripheral-signal only condition. These findings are in accord with those of Experiment I. The present finding is more emphatic, however, and this is presumed to be due to the more difficult ' flight task ' employed in the present study. By inspection, no statistically significant difference between any two of the three ' master ' conditions on the ' miss ' criterion is apparent.

Finally, analyses of variance were performed on the tracking scores (integrated time off target) and the verbal task scores (written test errors). The results indicated no statistically significant differences among these scores for the various ' master ' conditions employed. These analyses were intended to serve as a rough check on whether variations in performance on these tasks had occurred and might thus have affected performance under the various ' master ' conditions.

Experiment III :

A Comparison of Visual and Auditory Master Signals Under Two Levels of Task Complexity

The third study extended Experiment II to a comparison of several different types of master visual and auditory indicators. The master indicators studied were a two-tone auditory signal, a one-tone signal, and two visual signals which differed in brightness. In order to gain some insight into the consistency of the results across task difficulty, two levels of flight-task difficulty were incorporated.

Apparatus and Procedure

The same FELIS apparatus, as modified for incorporation of the audio-signal generator was used. The one-tone master auditory stimulus was the same as that used in Experiment II—an intermittent (8 per sec, 25 per cent duty cycle) 1800 c.p.s. complex tone. The two-tone signal was an alternating 340 and 1800 c.p.s. complex tone, with the total cycle being presented eight times per sec. The high and low components of this master auditory signal were of 25 and 75 per cent duty cycles, respectively. The intensities of both the auditory signals were maintained at a constant level of 83 dB.

The master visual indicator was a yellow Dialight fixture, No. 35410-XP13-313A. Brightness level I was identical with that employed in Experiment II (0·17 ft lamberts). Brightness level II was 0·78 ft lamberts : it was employed in an attempt to obtain an attention-arresting device that was superior to the one previously used. When the experimental design called for a visual master, it was illuminated simultaneously with one of the four peripheral light indicators. The peripheral lights were at the same brightness level as that of the master light in use.

The master visual indicator was positioned directly forward, 15° down from the horizontal visual axis, and 28 in. away from the subject's eyes. The peripheral indicator bank was located 20° to the right of the sagittal axis, 24 in. from the eyes and 46° down, and 20° away from the perpendicular to the visual axis. A 9-channel Roto-Tellite No. 15–100 assembly, containing 9 legend sub-units, composed the peripheral cautionary display. Each sub-unit measured $1\frac{1}{4}$ by 5/16 in., and, when activated, presented legend information in aviation red against a black background. The legends thus illuminated were PRESS LOW, CARB AIR, OIL HOT, and CANOPY, but no essential meanings were associated with these particular legends used. A bank of push buttons directly forward and 50° down, angled so as to be convenient to the subject, contained the four buttons used for extinguishing the peripheral light indicators. A legend corresponding to that found on the peripheral indicator was stencilled next to each appropriate button.

The experiment was run under ' night ' conditions only. Red illumination was provided in a manner identical to that used in Experiment II. Subjects were dark adapted as before.

Twelve male university students ranging in age from 18 to 22 years were used as subjects, none of whom had been used previously. They were paid on an hourly basis and advised that a bonus would be given for ' good ' performance.

Subjects were required to perform a compensatory tracking task involving either a single tracking meter or three separate meters positioned as follows : (1) directly forward and 25° down from the horizontal visual axis ; (2) 22° down and 27° to the left of the sagittal axis ; (3) 52° down and 42° to the left of the sagittal axis. The single meter task used the third meter only. All meters were approximately 28 in. from the subjects' eyes. The compensatory tracking tasks had to be performed while attending to the same prose passages as those used in Experiment II, heard against a background jet-aircraft noise. The secondary task was to respond to the various peripherally located legend-type signals presented in conjunction with the master signals.

A ' treatment × subjects ' three dimensional design was used. The six runs comprising an experimental session were each divided into 12 blocks, and each block contained eight presentations of one of the four master indicators. The order in which the blocks were presented was counterbalanced for the different subjects. Only one level of task difficulty was used in any one run. The time lapse between cautionary stimuli within each block was varied randomly from 18 to 96 sec throughout all runs. Each subject was presented with each of the four cautionary stimuli 24 times—a total of 96. These were divided equally over the two task levels.

Results

As in Experiment II, a ' miss ' was counted if a signal was not responded to within 5·5 sec. Again the first and second misses were assigned a value of 5·5 sec, the third a value of 5·75 sec, and the fourth and later misses, 6·25 sec.

The results of an analysis of variance of the 96 mean response times (8 per subject) are presented in Table 7. It may be concluded with acceptable statistical confidence that : (1) response time was shorter on the one-meter tracking

Table 7. Analysis of variance of response times (Experiment III)

	Degrees of freedom	Mean square	F	P<
Task (A) levels	1	4·09	10·49	0·01
Brightness and tone (B)	3	5·63	35·2	0·001
Subjects (S)	11	1·13	9·42	0·001
AB	3	0·07	0·58	—
BS	33	0·16	1·33	—
AS	11	0·39	3·25	—
ABS	33	0·12	—	—
Total	95			

task than it was on the three-meter ; (2) differences in response time were associated with master cautionary stimuli presented. In order to determine further which of the master signals produced the shortest response times, a test of critical difference (Lindquist 1953, p. 93) was performed. The results of this test are presented in Table 8. Within each task level : (1) the two-tone

Table 8. Tests of critical difference by task levels among master cautionary indicators (Experiment III)

Type of master signal	One-meter task			Three-meter task		
	BII	AI	AII	BII	AI	AII
BI	0·52*	0·58*	1·09†	0·72†	0·82†	1·27†
BII	—	0·06	0·57*	—	0·10	0·55*
AI	—	—	0·57*	—	—	0·45*

BI = Brightness level I. AI = One-tone auditory.
BII = Brightness level II. AII = Two-tone auditory.
Significance levels are indicated as follows : * $P<0.01$. † $P<0.001$.

master auditory signal resulted in significantly shorter response times than any of the other three master signals, (2) both the one-tone auditory signal and the brighter of the two master lights result in significantly shorter response times than the dimmer master light, and (3) the one-tone auditory signal and the brighter master light were equally effective.

Table 9 presents the numbers and percentages of ' misses '. Although the total number of ' misses ' on the three-meter tracking task was more than twice that of the one-meter task, a Wilcoxon matched-pairs signed-ranks test (Siegel, 1956) failed to indicate the difference as statistically significant. However, when the same technique was applied to all pairs of cautionary stimuli within each task level, it was found that in the three-meter task, Brightness II and the two-tone auditory master were significantly superior to the one-tone signal at the 0·05 and 0·02 levels of confidence respectively. It is also of interest to note that for both task levels, the two-tone auditory and Brightness Level II masters gave the fewest ' misses '.

The integrated-time-off-target data for the tracking tasks strongly indicated that the scores were significantly better on the one-meter task than on the three-meter. An analysis of variance yielded an F value significant beyond the 0·001 level of confidence.

Table 9. Numbers and percentages of ' misses ' (Experiment III)

Type of master signal	One-meter task		Three-meter task	
	Number	Per cent of total responses	Number	Per cent of total responses
Brightness level I	5	3	14	10
Brightness level II	2	1	6	4
One-tone auditory	14	10	22	16
Two-tone auditory	2	1	5	3
Total	23	4	47	8

Experiment IV :

Effects of Variations in Caution Displays of the Legend Type, Master Signal Present and Absent

Lensed fixtures of the legend type have recently been favoured for the presentation of warning and cautionary information. Lighting of the lamps contained in the fixture causes the legend to appear on the lens. The purpose of the fourth experiment was to compare black letters on an illuminated background (Positive displays) with illuminated letters on a dark ground (Negative displays) as peripheral caution indicators. This comparison was made with and without a master signal present.

Apparatus and Procedure

The subject's primary task was again multiple compensatory tracking, and his collateral task responding to the caution light indicators when they appeared. The three-meter task of Experiment III was used. Only one indicator bank, containing nine lights was employed for presenting the peripheral cautionary stimuli. It was located 20° to the right of the subject's sagittal axis, 46° down from the horizontal visual axis, and 24 in. from the eyes, and was mounted 20° from the perpendicular to the line of vision. Associated with this single panel of lights were three banks of push buttons. Each bank contained nine buttons, arranged so that a particular button on any of the three banks controlled the spatially corresponding indicator light. The buttons in the individual banks and the corresponding lights were arranged in squares consisting of three rows of three units each. One bank of push buttons was located directly forward, and the others on either side of the subject. The master indicator was positioned directly forward, 15° down from the horizontal visual axis, and 28 in. from the eyes.

All peripheral and master caution stimuli were aviation yellow. Three digit heights, $\frac{1}{8}$ in., $\frac{1}{4}$ in., and $\frac{3}{8}$ in., with a height to width ratio of 5 : 3 were employed. Stroke widths were 12 per cent of digit height. Three digits, ' 5 ', ' 6 ', and ' 8 ', were used as indicator legends. These numbers have been shown to possess approximately equal legibility (Tinker 1951). Each of the three numbers referred to one of the three banks of push buttons. The subject's task, when a cautionary display was illuminated, was first to identify the

number and associate it with the proper push-button bank. He then located within that bank the specific button to extinguish the light.

The lens surfaces were all 1 in. in diameter and were set in a Dialight fixture No. 35410-XP13-313A, containing two No. 313 lamps. The light intensity of both peripheral and master indicators was the same and of a value chosen to be just above recognition threshold, but sufficient to ensure discrimination and response within the maximum time allotted (in the present experiment, 6·0 sec). Aviation red flood illumination in the dark surround was obtained through the use of two side-mounted Grimes B-4745-3 and two overhead-mounted Soderberg C-4A adjustable fixtures. These two light sources provided 0·06 ft lamberts on the flight-task dial and push-button surfaces. To simulate night cockpit conditions still further, six Dialight fixtures, each with a 1 in. diameter aviation red lens adjusted to the same brightness as the caution light stimuli, were mounted in two vertical rows of three, one row adjacent to the caution lights to the right of the subject and the other to the left. These six ' surround ' fixtures remained illuminated throughout.

The subjects were ten male university students ranging in age from 19 to 30 years. An H-4 crash helmet with 58-H-4 liner, earphones mounted, was worn by subjects during the experimental runs, which were preceded by a 15 min dark adaptation period.

Subjects were advised that they could earn a monetary bonus by scoring high, in addition to their time payments. These bonus payments, together with information about their scores, were intended to raise the subjects' motivation.

Each subject was tested in a single session which included six experimental runs of 12 min, during each of which sixteen caution-lights were presented. A 20-min rest was inserted at the mid-point.

The variables under study, i.e. :

Master indicator (' On ' and ' Off '),
Displays (Positive or Negative), and
Digit size ($\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{3}{8}$ in.)

were included in a $2 \times 2 \times 3$ design. Each of the resulting twelve conditions was included at least once within any single run of sixteen cautionary presentations. The overall plan of stimulus presentation was to maintain randomness in all instances where balance was not essential, both as to order of presentation and time of presentation. The three digits used were balanced equally among the twelve conditions since each referred to a different bank of buttons. A limited degree of randomness was available within this balance, and was utilized in all instances. Eye fixation immediately preceding the presentations of cautionary stimuli was controlled by having the subject fixate the centre milliammeter. The total number of meter fluctuations in the flight-task was held constant for each run, and each run received an equal number of fluctuations on each of the three meters.

Results

A ' miss ' was scored if no response was made within 6 sec. Response times of 6 sec were assigned to the first and second misses, of 6·25 sec to the third miss, and of 7 sec to the fourth and subsequent misses. The mean response

times are presented in Table 10 and an analysis of variance based on a total of 120 mean values (12 means per subject) is presented in Table 11.

Table 10. Mean response times (in seconds) for twelve conditions (Experiment IV)

Digit size (in.)	Master on		Master off		Grand mean (digit size)
	Positive	Negative	Positive	Negative	
$\frac{1}{8}$	3·61	3·73	4·35	5·47	4·29
$\frac{1}{4}$	3·07	3·72	3·83	5·92	4·14
$\frac{3}{8}$	3·40	3·57	3·86	4·99	3·95
Grand mean	3·53		4·74		

Positive grand mean : 3·69.
Negative grand mean : 4·57.

Table 11. Analysis of variance of response times (Experiment IV)

Source	Degrees of freedom	Mean square	F	P<	F ratio divisor
(1) On-Off	1	447,618·6	82·78	0·01	Ss × On-Off
(2) Positive-Negative	1	232,231·9	110·60	0·01	Combined residual
(3) $\frac{1}{8}$-$\frac{1}{4}$-$\frac{3}{8}$ (size)	2	11,516·4	5·48	0·01	,,
(4) Subjects (Ss)	9	34,690·1	16·52	0·01	,,
(5) On-Off × Positive-Negative	1	95,372·6	45·42	0·01	,,
(6) On-Off × Size	2	7,338·8	3·49	0·05	,, ,,
(7) Positive-Negative × Size	2	18,374·8	8·75	0·01	,, ,,
(8) On–Off × Positive-Negative × Size	2	1,848·8	1·21	—	Residual
(9) Ss × On-Off	9	5,407·2	2·58	0·05	Combined residual
(10) Ss × Positive-Negative	9	1,939·4	1·00	—	,, ,,
(11) Ss × Size	18	3,082·5	1·47	—	,, ,,
(12) Ss × On-Off × Positive-Negative	9	1,449·5	1·00	—	Residual
(13) Ss × On-Off × Size	18	2,379·2	1·56	—	,,
(14) Ss × Positive-Negative × Size	18	2,744·3	1·80	—	,,
(15) Residual	18	1,528·8			
(16) Combined Residual	65	2,099·8			
Total	119				

The F ratios pertinent to all three main effects (Master On-Off, Positive-Negative display, and digit size) were significant and thus indicate that: (1) the master indicator lowered response time, (2) Positive displays were superior to Negative, and (3) larger digits tended to be reacted to more quickly than smaller.

The differences among the three digit sizes were subjected to *t* tests. For this purpose the Positive and Negative displays were treated separately as well as compositely so as to identify more clearly their individual contributions. These data are presented in Table 12. In the case of the Positive displays (the superior mode of presentation), the $\frac{1}{4}$ in. digit size had a significantly shorter response time than the $\frac{1}{8}$ in. size, although its time was not significantly

Table 12. *t* tests of response times in relation to digit size (Experiment IV)
(One-tailed test)

	Positive only		Negative only		Composite	
	t	P<	*t*	P<	*t*	P<
$\frac{1}{8} \times \frac{1}{4}$	4·17	0·01	1·69	—	1·78	—
$\frac{1}{4} \times \frac{3}{8}$	1·00	—	5·88	0·01	1·54	—
$\frac{1}{8} \times \frac{3}{8}$	1·47	—	2·01	0·05	2·17	0·05

different from that of the $\frac{3}{8}$ in. size. With Negative displays the two smaller sizes both yielded significantly longer response times than the $\frac{3}{8}$ in., but did not differ from each other.

The numbers of 'misses' in the different conditions were compared by the Wilcoxon matched-pairs signed-ranks technique. The results are shown in Table 13.

Table 13. Wilcoxon matched-pairs signed-ranks analysis of 'miss' data (Experiment IV)

Condition	Percentage of total presentations missed	Against condition	Percentage missed	Value of 'T'	Significance level (one-tailed)
Master Off	38·0	Master On	4·6	0	0·01
Negative	31·0	Positive	11·9	0	0·01
$\frac{1}{8}$ in. Size	24·1	$\frac{1}{4}$ in. Size	21·6	12	—
$\frac{1}{4}$ in. Size	21·6	$\frac{3}{8}$ in. Size	18·8	13	—
$\frac{1}{8}$ in. Size	24·1	$\frac{3}{8}$ in. Size	18·8	9	0·05
$\frac{1}{4}$ in. Negative	35·6	$\frac{1}{8}$ in. Negative	33·1	16	—
$\frac{1}{4}$ in. Negative	35·6	$\frac{3}{8}$ in. Negative	24·4	0	0·01
$\frac{1}{8}$ in. Negative	33·1	$\frac{3}{8}$ in. Negative	24·4	7	0·05
$\frac{1}{8}$ in. Positive	15·0	$\frac{1}{4}$ in. Positive	7·5	2	0·02
$\frac{3}{8}$ in. Positive	13·1	$\frac{1}{4}$ in. Positive	7·5	11	—
$\frac{1}{8}$ in. Positive	15·0	$\frac{3}{8}$ in. Positive	13·1	10	—

Comparison of the 'miss' data with the results of the analysis of variance performed on the response times (Table 11) indicates that significant differences were obtained in both instances between the Master On-Off variables and between the Positive-Negative display variables. Similarly, the $\frac{1}{4}$ in., digit size (Positive display) was again significantly more effective than the $\frac{1}{8}$ in. for the Positive display, and the $\frac{3}{8}$ in. digit size was more effective than the $\frac{1}{4}$ in. and $\frac{1}{8}$ in. sizes for the Negative.

The percentages of misses for the Negative display × Master On-Off and the Positive display × Master On-Off conditions are not included in Table 13. For Negative displays there were 5·8 per cent misses with the master on as compared with 56·3 per cent with it off. For Positive displays, there were 3·3 per cent misses with the master on, as compared with 20·4 per cent with it off. The interesting point here is perhaps not that the Positive and Negative displays differed so much with the master indicator off, but that they differed so little with the master indicator on. These findings are again in agreement with the response time data.

Concluding Note

The hazards of predicting from the findings of laboratory experiments to real life operational situations are well known, but so far as they go, the results of the present studies suggest the following conclusions for the design of cautionary warning signals especially in aircraft.

1. A master indicator, either auditory or visual, used in conjunction with a peripheral signal improves the attention-arresting value of the peripheral signal.
2. A fluctuating, two-tone auditory master signal is superior to a one-tone. The latter is equal in effectiveness to a bright visual master signal.
3. A one-tone auditory master signal is superior to a dim visual master. The combined presentation of these two results in no improvement over the auditory alone.

4. In the absence of a master signal, legend-type displays consisting of black letters on an illuminated background are clearly superior to displays consisting of illuminated letters on a dark ground as peripheral indicators. With a master indicator present, however, differences in the effectiveness of the two types of display are small.
5. Under the conditions of the present experiments $\frac{1}{4}$ in. digits appeared satisfactory for displays consisting of black digits on an illuminated background, but for illuminated digits on a dark ground a height of at least $\frac{3}{8}$ in. is needed.

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On a réalisé quatre expériences dans le but de dégager des méthodes optimales de présentation de l'information d'avertissement. Dans chaque expérience la tâche principale consistait en une épreuve de " centrage " multiple, alors que la tâche secondaire consistait à répondre à divers signaux avertisseurs.

L'expérience I étudie les effets d'un signal principal central sur les réponses aux dispositifs avertisseurs périphériques.

Les expériences II et III comparent les efficacités de divers types de signaux avertisseurs principaux, soit visuels, auditifs ou auditifs-visuels dans des tâches comportant divers niveaux de complexité.

L'expérience IV étudie des dispositifs avertisseurs à lentille présentant l'information sous forme de légende.

Résultats principaux :

Lorsqu'il s'agit de répondre à une série de signaux avertisseurs en présentation périphérique, on constate que :

(1°) Le temps de réponse et le nombre de non-réponses diminuent par l'adjonction d'un signal principal.

(2°) Les signaux principaux auditifs sont supérieurs aux visuels.

(3°) Un signal principal auditif-visuel réduit au minimum les non-réponses.

(4°) Un signal principal auditif bi-tonal est supérieur au mono-tonal.

(5°) Quant aux signaux à légende lumineuse, ceux qui comportent une légende foncée sur fond éclairé sont supérieurs à ceux qui comportent une légende éclairée sur fond noir.

(6°) Dans ce dernier type de signaux, ceux à corps de lettre de 1/4 in. (6,4 mm) sont supérieurs à ceux à corps de 1/8 in. (3,2 mm) (rapport hauteur–largeur 5 : 3), mais ne diffèrent pas significativement de ceux à corps de 3/8 in (6,9 mm).

Die besten Methoden der Darbeitung von Warn-Signalen wurden in 4 Experimenten untersucht. In jedem Experiment bestand die Hauptaufgabe darin, mehrere Instrumente fortwährend auf Null zu regeln, während die Beantwortung verschiedener peripher liegender Warn-Signale die Nebenaufgabe bildete. Im Experiment I wurde der Einfluss eines zentral liegenden Weck-Signales (das zum Hinweis auf periphere Warn-Signale gleichzeitig mit diesem gegeben wurde) auf die Beantwortung peripherer Warn-Signale untersucht. Die Experimente II und III prüften die Wirksamkeit verschiedener Typen von Warn-Signalen (optische, akustische und optisch-akustische) unter verschiedenen Schwierigkeitsgraden der Hauptaufgabe. Im Experiment IV

wurde die Form aufleuchtender Warn-Schriften untersucht. Die Hauptergebnisse der 4 Experimente ergaben für die Beantwortung vielfacher peripherer Warn-Signale folgendes :

(1) Die Anwendung eines zentralen Weck-Signales verringert die Zeit der Beanwoetung und die Zahl der übersehenen Signale.
(2) Akustiche Weck-Signale sind optischen überlegen.
(3) Der Gebrauch optische-akustischer Weck-Signale führt zu der geringsten Zahl übersehener Signale.
(4) Ein Doppel-Ton-Eeck-Signal ist besser als ein Ein-Ton-Weck-Signal.
(5) Aufleuchtende Schrift-Signale sind besser mit dunklem Text auf beleuchtetem Hintergrund als umgekehrt.
(6) Die Buchstabenhöhe (Höhe : Breite = 5 : 3) ist besser 6 mm als 3 mm, aber nicht signifikant besser als 9 mm.

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PERCEPTION AND ALERTNESS

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Many of the published results of laboratory studies of vigilance do not indicate what occurs in practical watchkeeping tasks. Thus, for example, the ' fatigue ' effects which Mackworth studied intensively, are seldom found in the more important military watchkeeping tasks. Again the relationship between rate of stimulation and probability of response appears to be more nebulous in protracted practical tasks than it is in a closely controlled laboratory study such as Deese's. Furthermore we find that performance in practical tasks is generally very poor compared with what seems to be theoretically possible. This effect can be seen also in some of the well known laboratory results, but there has been little discussion devoted to it.

This paper reformulates current ideas of perceptual organization in watchkeeping, and attempts to explain why there are discrepancies of the kind just mentioned. Particular emphasis is placed upon the type of investigation which needs to be pursued in order to resolve present difficulties.

§ 1. Introduction

The study of vigilance started some twenty years ago with the prime object of reaching an understanding of the behaviour of operators carrying out military tasks, notably those of radar, asdic and visual lookouts ; and, to a large extent, the continuation and extension of the earlier work has been sustained by military interests. Quite properly, most researchers have avoided the considerable instrumentation problems of real military tasks, and have attempted to build what were guessed to be the right ' psychological variables ' into more readily handled test situations ; but it is unfortunate that, so far, the hypotheses examined have not always greatly illuminated our understanding of military search tasks. Whenever we have studied real military watchkeeping tasks, we have achieved some results which could not have been predicted from published test data, and, indeed, we have often found the published material quite misleading. Two instances may be mentioned :

(i) Until recently, at least, researchers have been greatly preoccupied with what might be termed the Mackworth ' A ' effect. This effect appeared in the Clock Test (Mackworth 1950) in which the watchkeeper's performance deteriorated after about 30 min and then was maintained at about the same impoverished level for a further 90 min. This form of behaviour has never been found in any closely simulated radar or asdic search. Occasionally, when operators have been subjected to an arduous series of watches a ' fatigue ' effect has been observed, but it has been a continuous degradation of performance throughout the watch. More commonly there are no ' fatigue ' effects during continuous two-hour watches. What we might call the Mackworth ' B ' effect also leads to some disconcerting observations. This effect was seen in the first 30 min of the Clock Test, where operators missed about 15 per cent of the signals which a completely efficient operator would have detected (in the subsequent 90 min the rate of missed signals increased to nearly 30 per cent). In other words, the vigilance situation was such that operators were immediately inefficient at the beginning

of a watch. In military tasks we do find this ' B ' effect, and it is the effect which plainly limits the efficiency of a search system. Despite this, and the fact that the ' B ' effect is a little larger than the ' A ' effect (at least in Mackworth's own experiments) the ' B ' effect has received little attention : it is often quite ignored while theories explaining the ' A ' effect are developed in profusion, and experiments to test such theories are multiplied.

(ii) More recently we have been in similar trouble with what might be called the Deese effect. Deese (1955) showed that there was a fairly regular relationship between rate of signal presentation and probability of detection. This is interesting because it suggests that by artificially increasing signal frequency in a search task we might keep operators alerted. In fact this does not work out as happily as Deese's results would suggest. In the complexities of real tasks behaviour is very variable. We can see a marked change of behaviour at some critical signal frequency, but manipulation of this parameter over a wider range of values does not appear to affect behaviour appreciably.

There are other more diffuse criticisms of most published work on vigilance. Thus, for example, although vigilance tasks are supposed to be concerned with the detection of ' rare ' signals most researchers have used a rate which is quite high compared with rates in some of the more important operational tasks. Again, social isolation, which has been a deliberate feature of most laboratory researches, may be an interesting psychological phenomenon, but is not relevant to most military watchkeeping tasks. Further, scarcely any published work refers to experiments which have studied behaviour over several watches. The latter is an important omission because, in studies of military tasks, significant changes of vigilant behaviour have been observed over periods totalling as little as 20 hours' watchkeeping.

All these points could be amplified and attempts could be made to explain differences between apparently conflicting experiments. It is, however, doubtful whether any conclusive understanding would be attained. The experiments, which would have to be compared, differ in several respects, so that it is impossible to assign a difference of behaviour to a different handling of a single parameter. Indeed one's criticisms of vigilance studies as a whole reduce to this : that techniques are insufficiently standardized, that researchers are somewhat whimsical and give insufficient thought to planning work so that it will lead to a real extension of knowledge rather than add another isolated fact, and, most important, that some aspects of vigilant behaviour which are vital in real tasks have so far received insufficient attention. The object of this paper is to suggest a few points about techniques and about design of experiments which might improve matters.

§ 2. The Sensory Input and Scaling Problems

Experiments have been designed to study patterns of signal presentation, effects of motivation, hot and noisy environments, drugs, sleep deprivation and so on ; but surprisingly little attention has been given in these studies to specifying accurately the magnitude of the signals used. Broadly speaking, a vigilance task is one in which an operator searches for infrequent weak signals,

and few researchers have gone much beyond indicating that their signals were ' weak '. In this neglect we may have a large part of the reason for difficulties of reconciling divergent outcomes from experiments.

It seems to be the general view that vigilant behaviour is to be regarded as dependent upon a central process and that we should not expect different laws to apply, for example, to visual and auditory vigilance, or to two types of visual task. This view does not make sense unless we can also arrive at an idea of ' equivalent inputs ' to different sensory pathways. In other words if we adjust the pattern of signal presentation and the size of signals in two types of vigilance task until similar patterns of gross behaviour are observed, we cannot assume that we have demonstrated the probable existence of common central processes unless the two inputs can also be seen to be equivalent in some other sense than that of producing the same gross behaviour. In other words we need a logical connection between stimulus parameters to correlate with empirical measures of behaviour. Clearly we must try to specify at the outset of comparative experiments what sort of equivalence the signals could take. This is not too difficult to do as a theoretical exercise, though the practical realization of equivalence might be very arduous.

Let us consider first what is probably one of the simplest cases. Suppose we want to say something about the equivalence of inputs in two search tasks consisting of :

Task A—An auditory task in which tonal pulses are to be detected in the presence of white noise (cf. Elliott 1957).

Task B—A fairly exact visual analogue of Task A where a colouration is to be detected when it appears over the whole of a very large evenly illuminated white screen, so that the observer's visual field is a uniform white which will be faintly coloured when a signal is presented.

In either of these tasks there would be no technical difficulty in scaling the stimulus. We might first establish a 50 per cent recognition differential, and then we ought to establish a scale of just-noticeable differences (J.N.D.s) extending from the recognition differential up to large signal intensities.

Now it would be natural to hypothesize that vigilance situations like these Tasks A and B should yield identical patterns of response behaviour if the patterns of signal presentation were the same, and if the signal strengths were the same in terms of J.N.D.s. If this did not turn out to be the case then we should seriously doubt the theory of a common central ' mechanism ' of vigilance. However, no one has yet carried out this comparatively simple experiment.

Now consider another pair of tasks :

Task C—This is like one of Bakan's (1957) : numbers are flashed on a screen and certain specified numbers or sequences of numbers constitute the signal to be detected, while all other numbers or sequences constitute the noise.

Task D—This is the exact auditory analogy of Task C, the same numbers being spoken and presented via earphones.

Provided we use identical signalling programmes, tests in Tasks C and D should yield equivalent results if our hypothesis of a common central function

is correct. We scarcely need to scale the intensities of these signals for this limited comparison, provided the intensities are fairly high, but scaling problems certainly arise if we want to extend our tests to compare behaviour in the four tasks, A, B, C and D. However it is not satisfactory to confine scaling to intensity functions ; it is feasible to degrade Tasks C and D so that signal-to-noise becomes a prime determinant of detection, but the parameter which is normally important, and certainly is of greater psychological interest here, is the information contained in the tasks. On the other hand information is not a parameter normally considered in handling tasks like A and B, although, if we increase the complexity of these tasks by, for example, having a rhythmic pattern of tones or colours, we ought to scale in terms of information. In any case, the normal form of Tasks A and B can be regarded as equivalent in information to Tasks C and D in the special case where the number to be detected is one digit and the noise is another digit.

It becomes clear then that to use our four tasks to demonstrate the existence of equivalent behaviour for equivalent input involves scaling in at least the two parameters mentioned, and we must use unusual forms of all the tasks. Alternatively, we can see that it should not be surprising if the use of the tasks in their normal forms leads to differences of gross behaviour. It thus seems premature to build up general theories of vigilance until we have at least a few experiments in which full attention is given to scaling both the parameters of information and intensity. Before discussing the design of such experiments, something must be said about ' coupling ' the task to the sensory input, a factor which must be at the back of the minds of many researchers but which receives little overt consideration in theoretical discussions.

§ 3. Coupling the Task to the Operator

By ' coupling ' is meant an arrangement of the task so as to ensure that the signal put out by the experimenter's apparatus gets into the appropriate sensory input of the vigilant subject. The physical output is more tightly coupled to the observer in some familiar vigilance tasks than it is in others. For example, in general, auditory tasks are more tightly coupled than visual. This will become obvious if we consider instances. There will be a choice of ways of processing and presenting some of the information contained in electrical signals such as those received in radar and asdic systems. If the chosen information is presented via earphones we can be quite sure that the cochlea receives an input related in a fixed, if not known, way to the physical parameters of the display. On the other hand, if the information is presented on an oscilloscope we cannot be sure that the retina receives the stimuli designed for it. Head and eye movements, blinking, focusing, will determine the input. In so far as we control or measure the subject's movements, etc., the indeterminacy is reduced ; but both control and measurement are difficult and, generally, control would only enable us to determine when the designed input had been received : it would not be possible to predict that the input would be received on the next occasion, so that programming one's experiments would in any case be imprecise.

These considerations suggest that, other things being equal, an auditory vigilance task should always, or nearly always, be preferred to a visual one.

Among visual tasks it is, however, possible to vary the coupling efficiency. Thus perfect coupling is obtained, although in a somewhat esoteric manner, by shining a bright light through the closed eyelids (eliminating blinking) and modulating the brightness to produce a signal. A task of detecting modulation of light, or detecting colour changes, on a uniformly illuminated screen surrounding the subject or subtending a very large visual angle would be nearly perfectly coupled. Coupling efficiency clearly diminishes as the illuminated area is reduced, though some compensation can be made for diminished area by restricting head movements. Thus if a screen subtends a visual angle of say about 60° and head movements are restricted by the use of pads, such as those in a dentist's chair, coupling will be quite good. If now the electrical signals of a radar or asdic system are used to modulate the brightness of this large screen we have a reasonably well coupled detection task. The usual method of presenting radar or asdic signals on a small oscilloscope is, by contrast, about as poor a form of coupling as could be devised. Of course, to achieve good coupling, as just suggested, information required for other purposes than detection is discarded. Moreover, achieving good coupling is not in itself a determinant of good detection : but some degree of coupling is a *sine qua non* of detection, and, therefore, detection will be improved by improving coupling.

From the pure researcher's point of view it seems preferable to get rid of the coupling factor by using such esoteric tasks as those which have been mentioned above. It is, admittedly, possible to measure eye-movements and thus to measure the coupling efficiency of any task, and thus make comparisons with inherently well-coupled tasks more satisfactory, but the measurement of eye-movements is not easy, and the experimenter will tend, needlessly, to overload his own capacity for experimenting.

§ 4. Central Processes and Design of Experiments to study them

On the whole, experiments studying vigilant behaviour appear to be conceived and eventually discussed as if there were a central mechanism which will be solely concerned with the particular task which the experimenter presents. This seems a most unnatural supposition, and no one seems to make it except when designing experimental work on vigilance. Most people would agree that attention is a phenomenon of shifting focus, and that, probably, when the focus is at one point sensitivity elsewhere is necessarily reduced. Yet though the technical problems do not seem to be too severe, the present writer does not know of any experimental work on vigilance which is designed around such a view. Broadbent (1957a) has made the point that ' in a pure vigilance situation there is no way of telling how the man is behaving during the time between signals. In more active tasks we can record what he is doing more continuously and I personally believe that this sheds a great deal of light on results from vigilance tasks.' This sort of comment seems to be correct and valuable, but it does not go quite far enough. Our real research problems are to find out about behaviour in the gaps between signals in a pure vigilance task and I do not think the task is as impossible as Broadbent suggests. This ' gap ' behaviour will be directed towards sensory inputs other than the task input, and we can only study it by the use of two or more tasks carried out simultaneously. One or more of these can be ' pure ' vigilance tasks with rare

weak signals, the others must be continuous ' active ' tasks which load the subject and tend to prevent him from attending to stimuli which are not under our control, so that we can find out to some extent where his attention is focused and how it shifts. Means of accomplishing this can be made clearer by first describing a model of a vigilant machine : the tests we should apply to such a machine will be fairly obvious and will suggest what form tests of a vigilant man should take.

The model is clearly similar in most respects to Broadbent's (1957 b), and the implied theory of vigilance is clearly similar to his ' filter ' theory (1958). The advantages claimed for the present formulation are, first, that due prominence is given to signal intensity, which Broadbent does not consider in any detail, and secondly, that programming experiments to test hypotheses seems to follow more naturally than it does from the filter theory.

§ 5. Characteristics of a Vigilant Machine

Let us consider a machine with the following specification.

(i) there are many inputs,

(ii) the signals fed to any input may be varied in intensity relative to a background noise,

(iii) the signals at any imput may appear in sequences, some of which form a pattern to be regarded as the ' significant input ' while all other sequences will be noise inputs. The complexity of the sequence will determine the information carried,

(iv) all inputs are connected within the machine via ' set ' switches to one terminal at which there is a trigger. The ' set ' switches determine the level of input signal required to actuate the trigger : in other words the ' set ' switch determines the sensitivity of the channel.

(v) A scanning switch shunts one of the set switches at a time so as to increase the sensitivity of that channel to a value greater than any which can be set in any other channel. The scan moves from channel to channel, according to some systematic programme—or perhaps at random.

(vi) if a signal in a channel not shunted by the scan switch is great enough to actuate the trigger, the scan immediately shifts to that channel. In other words *one* action of the trigger is to ' home ' the scan.

(vii) the output of the machine, which for our present purposes might be simply the operation of an alarm bell, is produced as an output from a computer. The computer itself is fed with inputs via the trigger: that is to say only signals large enough to actuate the trigger will pass to the computer,

(viii) further, the output occurs only after the scan has homed to the relevant signal channel. Response is, in fact, delayed until the scanning switch is set. A store in each channel is required, otherwise no response would normally be possible to a signal having a duration less than the time required for the scan to home.

We may briefly examine some of the general characteristics of such a machine. No input channel is ever so insensitive that a large signal will not

produce a trigger action ; but if too many large signals appear at different inputs the recovery time of the trigger, and the time for the scan to home, will limit the effective performance of the machine and may produce in the last event ' paralysis ' or ' hysterical ' behaviour. Thus adjusting too many of the ' set ' switches to high sensitivities would lead to breakdowns, and in using our machine we might want to discover an appropriate set of rules for optimum behaviour. The rules would depend upon probability/intensity functions at all inputs, the capacity of the computer, and the time delays in scan and trigger. However if we were to give the machine a ' pure ' vigilance task the obvious strategy would be to set all inputs but one to low sensitivity so that there would be very little chance of response except to the chosen task. It may be assumed that the normal scan could not be controlled, so that the weakest signals arriving at the chosen input would arouse responses only if the scan happened to be resting at the input at the time of arrival. If normal scanning is rather rapid, so that the scan rests in one channel for only brief periods, it is unlikely that the weakest signals will be detected. In fact, signals will normally need to reach levels determined by the maximum sensitivity obtained with the ' set ' switch. This sort of behaviour would explain the common finding in military tasks which I have called the Mackworth ' B ' effect.

If we were dealing with a physical machine of the type described we should certainly attempt to demonstrate its behaviour in response to a complex set of inputs. Thus, for example, by having a sufficiently rapid stream of signals in one channel the scan could be kept stationary. But if fairly intense signals appear in a second, or perhaps third or fourth channel, the scan must home to that channel ; and if the rates of signal presentation in the two or more channels are systematically varied we should get some idea of scan switching times.

So long as the information presented is uncomplicated, as for example in the elementary form of Tasks A and B described above, the machine will operate moderately well with signals applied at several inputs, provided the average rate of signal presentation is not too high. But if we loaded the computer by feeding complex information through one channel we should expect an immediate limitation to be placed upon the possibility of feeding even elementary information into other channels. To prevent breakdown we would set input sensitivities to low values, so that only really ' urgent ' (i.e. large) signals could actuate the trigger.

This physical machine crudely realizes some of our intuitions about our own perceptual and attentive behaviour. Its value lies in suggesting experiments rather than in any serious attempt to describe physiological mechanisms, and the experiments outlined seem to be feasible and not too impracticable to make upon a vigilant man. Perhaps the simplest realization of such a programme would be to use, say, the Tasks A, B, C and D already described above. Either C or D, or both, could be used in normal forms to load the computer, while we examine the probability/intensity functions for detection in normal forms of Tasks A and B. Yet the more crucial experiments will be obtained by demonstrating reciprocal relationships between tasks. Thus we should be able to demonstrate the probable existence of common vigilance mechanisms if we adopt unusual as well as normal forms of tasks, and, in successive experi-

ments, interchange the functions of tasks, using each to load the computer and to constitute a simple perceptual detection task (what Broadbent calls a 'pure vigilance task') in turn. We might, for example, use high intensity signals of complex pattern in Tasks A and B and low intensity signals of simple pattern in Tasks C and D as well as the normal reverse forms. Only experiments as complicated as this are likely to achieve such experimental verification of our central process hypothesis, and only such experiments are likely to make that definite step forward in the study of vigilance which will produce a sound theory of behaviour and the possibility of predicting behaviour in industrial as well as military watchkeeping.

This paper is based on one read to the Ergonomics Research Society on 31 March 1960.

Un grand nombre de résultats publiés à partir d'études de la vigilance effectuées en laboratoire ne fournissent pas d'indications sur ce qui se passe dans les tâches réelles de surveillance. Ainsi, par exemple, on retrouve rarement dans des tâches de surveillance recontrées dans l'armée les effets de la " fatigue " étudiés à fond par Mackworth. En outre, la relation existant entre la vitesse de stimulation et la probabilité de réponse semble être plus vague dans les tâches prolongées réelles qu'elle n'apparaît dans les tâches strictement contrôlées en laboratoire (ètudes de Deese, par exemple). Par ailleurs, il s'avère que la performance dans des tâches réelles est généralement très faible comparée à celle qui est théoriquement possible. Cet effet peut également être retrouvé dans certains résultats bien connus de laboratoire, mais a été peu explicité. Le présent article reprend les idées communément admises sur l'organisation de la perception en situation de vigilance et tente d'expliquer les incohérences mentionnées plus haut. L'accent est tout particuliérement mis sur le genre d'études qui devraient être entreprises pour résoudre ces difficultés.

Viele der veröffentlichten Ergebnisse von Laboratoriumsversuchen über Wachsamkeit zeigen nicht, was in der Praxis bei Ueberwachungsaufgaben geschieht. So werden z.B. die "Ermüdungs"-Effekte, die Mackwortn so gründlich studierte, bei den wichtigeren militärischen Ueberwachungsaufgaben selten gefunden. Auch scheint die Beziehung zwischen der Reizgrösse und der Wahrscheinlichkeit einer Beantwortung bei ausgedehnten praktischen Arbeiten sehr viel undurchsichtiger zu sein als bei einer streng kontrollierten Laboratoriums-Untersuchung wie der von Deese. Weiterhin finden wir, dass die Leistung bei praktischen Aufgaben im allgemeinen sehr dürftig ist, verglichen mit dem, was theoretisch möglich scheint. Diese Wirkung kann man auch in einegen gut bekannten Laboratoriums-Resultaten beobachten, doch ist ihr bis jetzt wenig Aufmerksamkeit geschenkt worden. Die vorliegende Arbeit formuliert geläufige Ideen zur Wahrnehmungs-Organisation bei Ueberwachungsaufgaben neu und versucht zu erklären, warum es die erwähnten Unstimmigkeiten gibt. Besonderer Wert wird auf das Untersuchungsverfahren gelegt, das verfolgt werden muss, um die gegenwärtigen Schwierigkeiten zu lösen.

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AN EXPERIMENTAL INVESTIGATION OF SPEED CONTROLS FOR SEWING MACHINES

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A new method of speed control for sewing machines used in the shoe industry was studied in a series of experiments. The skill requirements of the task were examined and the new control was tested both in the laboratory and in the factory. The justification for this kind of investigation is discussed.

§ 1. Introduction

The industrial sewing machine is normally driven by a belt and pulley system which is actuated by a clutch unit, as shown in Fig. 1 (*a*). When the operative presses the treadle the clutch moves into contact with a rotating flywheel and the machine stitches ; when the treadle is released a spring pulls the clutch off the flywheel and on to a fixed brake so that the machine stops. Briefly, the skill of the machinist involves picking up components, positioning them together and under the needle, clamping them in position by a presser foot or wheel and then guiding them as the machine stitches. A number of experiments were carried out to assess the adequacy of the above method of controlling machine speed for this task.

§ 2. Experiment I. Variation of Sewing Speed with the Curvature of the Required Line of Stitching

A skilled machinist was given the laboratory task of sewing along rows marked in white on a piece of black material similar to leather. The curves were all semi-circles of differing radii. The white marking lines were of widths varying from 1/32 in. to 1/8 in., and the subject was asked to sew within the line in each case. The sewing speed was recorded automatically using a voltage pen-recorder driven by a tacho-generator attached to the sewing machine.

Similar pen-recordings of machine speed for a variety of sewing tasks were obtained from operatives on production work. The required tolerance varies but in general a machinist is expected to keep within an imaginary line about 1/16 in. wide.

Every tachograph record taken in a factory showed machine speeds fluctuating between zero and maximum. For one operative on vamping the curvature of various parts of the vamp were measured approximately and the average speed at which the operative sewed round these curves was measured from the displacement of the pen-trace, ignoring phases when the machine was starting, stopping or stopped. These results and those from the laboratory experiment are shown in Table 1.

Table 1. Variation of average sewing speed (stitches per minute) with curvature of stitching

Radius of curve	Straight line	5 in.	4 in.	3 in.	2 in.	1¼ in.	1 in.	½ in.
Factory	1300					1140		840
Laboratory	1830	1180	1150	960	840		750	

* This work was carried out when the author was a member of the British Boot, Shoe & Allied Trades Research Association.

Comparing the two conditions it seems that the production machinist sews at a lower speed on the straight but does not reduce her speed to the same extent as curvature increases. This is reasonable since the straight rows are relatively shorter, but, on the other hand, the production machinist is highly practised on the particular curves of the vamp. In spite of this high level of learning there remains a considerable difference between machine speeds on the straight and on the curves. The maximum speed of these sewing machines is usually in the range 2000–2500 stitches per minute. It can be concluded that the machinist on skilled operations rarely uses this speed and spends a considerable proportion of her sewing time at much lower speeds.

§ 3. Experiment II. The Adequacy of the Standard Treadle and Clutch Mechanism as a Method of Controlling Machine Speed

Using simple engineering techniques an attempt was made to correlate machine speed with treadle pressure and treadle displacement. The power transmitter used for this experiment was a standard one in widespread use in the industry. There was no consistent relationship between treadle displacement and machine speed or between treadle pressure and machine speed. In the critical zone where the clutch face was just in contact with the rotating flywheel, the force on the treadle edge (5 in. from the axis of rotation) required to maintain equilibrium varied from 2 lb to 7 lb. A change of position of about 1/32 in. could have no effect or could cause the machine speed to change by more than half the maximum. The minimum treadle edge displacement required to vary speed from zero to near maximum and *vice versa* was about 1/16 in. Sample curves of speed against treadle displacement and pressure are shown in Fig. 2. These results are for one trial, for the standard transmitter the curve is displaced slightly right or left for each trial taken. That is the force and displacement at which the machine starts to stitch vary between trials although the shape of the curve is constant.

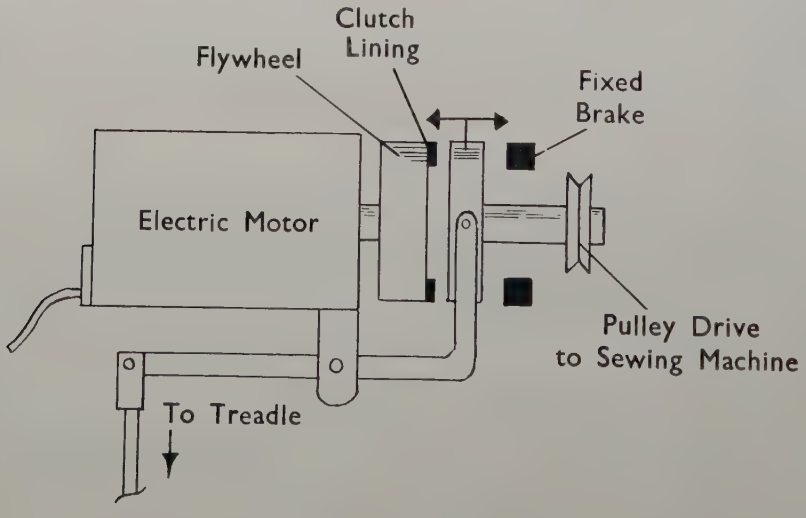

Figure 1 (*a*). Schematic drawing of standard transmitter.

In order to change the speed of the machine the operative must use her feet to change the pressure on the treadle and the position of the treadle. Superficially the making of correct treadle adjustment within the range given above would seem to be an impossible task. Nevertheless, it is clear from Experiment I that the task is within the capacity of an operative in that she can sew at speeds other than maximum.

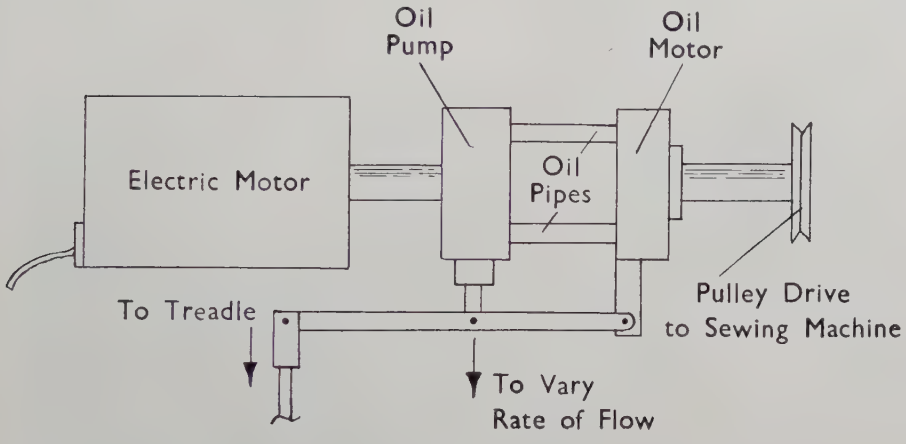

Figure 1 (*b*). Schematic drawing of variable-speed transmitter.

§ 4. Experiment III. Laboratory Comparison of Two Methods of Speed Control

The standard unit bench transmitter is an excellent mechanism for producing rapid acceleration and braking, but is clearly not suitable for producing controlled speeds other than the maximum.

Unfortunately, the requirements for a suitable variable speed are rather rigorous. To achieve the same acceleration and braking characteristics as the standard transmitter, it must be possible to move through the whole speed range in either direction in about 1/5 sec and speed changes must follow treadle movements without any appreciable time lag. It must also be possible to change speed under load and the speed must be independent of the load.

This specification appears to be best fulfilled by hydraulic units in which an oil pump driven by an electric motor drives an oil motor which in turn drives the sewing machine. Variable speed is achieved by varying the rate of flow either by a system of valves or by changing the output of the pump. This type of variable speed drive is shown diagrammatically in Fig. 1 (*b*).

One commercially available unit of this kind is made by 'Vickers (Detroit)' having been originally designed for aircraft turret control systems. Reconditioned units have been available at modest prices and several were obtained for use in the following experiments.

A synthetic sewing task was designed in which the operative sat at a sewing machine on a standard bench facing a display panel. This panel (1 ft $\times$ 2$\frac{1}{2}$ ft) was positioned at eye level about four feet from the operative and in a vertical

plane with the longer edge horizontal. Along the centre line of the panel there were 48 small neon bulbs arranged in vertical pairs, one inch apart. Thus there were two parallel rows each of 24 lights and these rows were also one inch apart. The bottom row of lights was controlled by the sewing machine—each time the machine completed a stitch one light would go out and the adjacent one to the right would come on. If the machine was stitching steadily the light would ' run ' along the row of bulbs from left to right. The upper light was used to provide ' targets '. Fig. 3 illustrates the experimental situation.

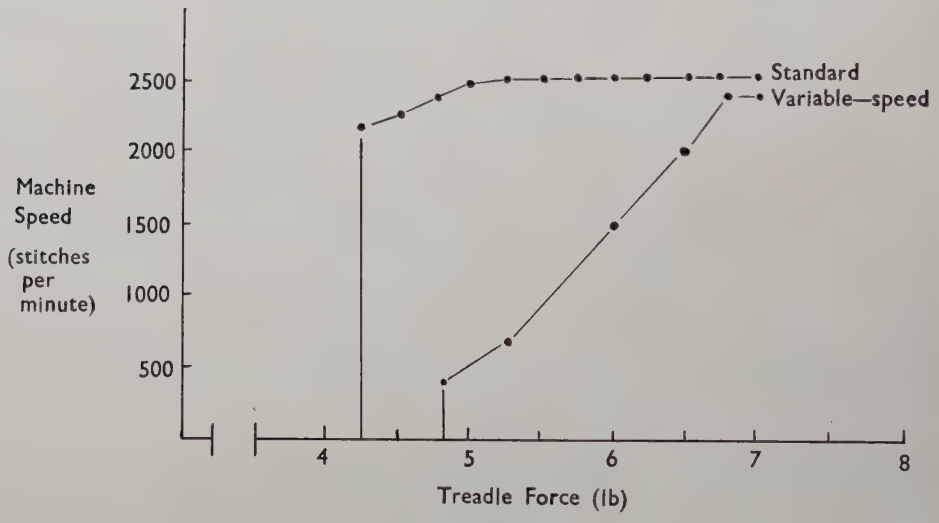

Figure 2 (*a*). Variation of machine speed with treadle force.

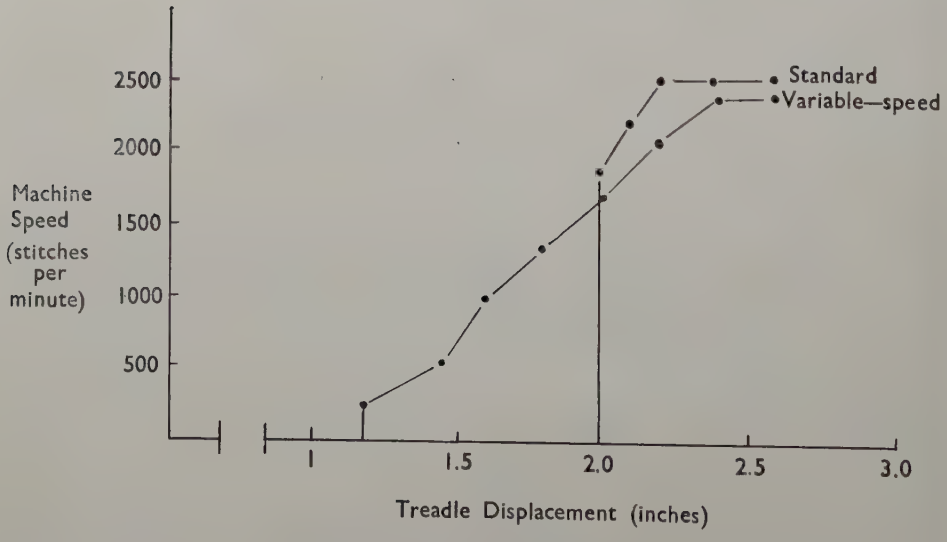

Figure 2 (*b*). Variation of machine speed with treadle displacement.

When the experimenter pressed the starting switch one of the lights in the upper row appeared. The subject then pressed the treadle, the machine stitched and the light on the bottom row would move from left to right. The subject's task was to release the treadle so that the light stopped below the target light on the top row. In other words, the subject had to produce a specific number of stitches as indicated by the position of the target light. If she succeeded in doing so, a bell rang and the target light was automatically moved to another position thus providing another target immediately after the controlled light returned to zero. If she failed, that is, if the controlled

Figure 3.

light stopped in a position other than under the target light, then the controlled system returned to zero and the subject could make a second attempt. The target light did not move until the subject had succeeded in stopping the controlled light beneath it. A trial consisted of the completion of 24 targets achieved. Each of the possible target lights appeared once, the order of targets was otherwise random.

Counters on the experimenter's control panel recorded automatically the total time for the trial and the number of errors made. A Setar (Welford 1952) was used to record in detail the reaction time between the appearance of the stimulus and the start of the response and the stitching time for each attempt. Correct and incorrect responses were also distinguished.

Forty female subjects were used, 20 were machinists and 20 were non-machinists. There were four experimental groups each containing ten female subjects, two of machinists on production work in a shoe factory, and two of non-machinists drawn from the laboratory staff of the Research Association. One of each type of group was given three trials with the standard control followed by three trials on the variable speed control. The other two groups were given three trials on the variable speed control followed by three with the standard control.

It seemed from inspection of the data that the transfer effects between the two tasks were small and positive in each case. If these are neglected gross scores can be obtained by ignoring task order and using only the results from the final trial on each transmitter. These are shown in Table 2.

Table 2. Results from final trial on each transmitter

Means per subject ignoring order of presentation. The standard deviations are shown in brackets

	Operators		Non-operators	
Number of subjects	20		20	
Transmitter	Orthodox	Variable speed	Orthodox	Variable speed
Total time (sec)	231 (71)	209 (56)	278 (77)	170 (30)
Number of errors	43 (18)	32 (22)	59 (25)	21 (10)
Average correct reaction time (sec)	0·81 (0·31)	0·66 (0·17)	0·70 (0·23)	0·59 (0·19)
Average correct response time (sec)	1·27 (0·49)	1·67 (0·71)	1·33 (0·61)	1·89 (0·70)
Average error time† per correct response (sec)	7·56 (2·56)	6·40 (2·66)	9·56 (3·18)	4·62 (1·24)

† (Total time—time for correct attempts) ÷ 24

The non-operators were faster and made fewer errors when using the variable speed transmitter. The same trend appeared for operators although in this case the result was not significant. The operators performed better than the non-operators when using the orthodox transmitter but the converse was true for the variable speed transmitter.

When the total time is separated into the components, it emerges that all the subjects spent most of their time making unsuccessful attempts. Comparing the two transmitters the reaction times are faster when using the variable speed transmitter but the response times (effectively the average speed of sewing) are slower.

As a matter of general interest the influence of the position in the layout on the average errors and reaction times was investigated. Errors were more or less uniformly distributed among the 24 stimuli. Reaction times were shorter for stimuli in the middle of the display as shown in Fig. 4.

The curve shows the mean reaction time for all subjects and all trials under both conditions. A parabola with a minimum at $x = 11{\cdot}1$, is a good

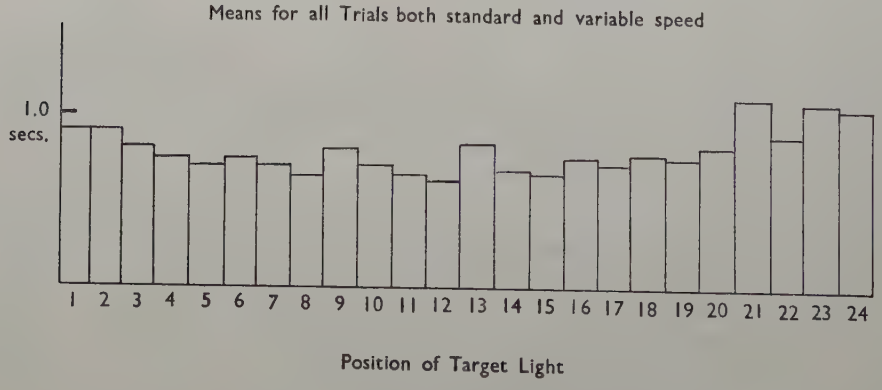
Means for all Trials both standard and variable speed
1.0
secs.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Position of Target Light

Figure 4. Reaction times for each target.

fit for this curve. The minimum is a significant distance to the left of the middle of the array ($x = 12{\cdot}5$). When the results for the operators and non-operators on each of the six trials are considered separately the same curve is a reasonable fit for each of the twelve sets of results, these being simply displaced along the time axis. (See statistical appendix.)

It is clear that the variable speed transmitter facilitates a better performance on this sewing task than does the orthodox control. This is true for subjects with many years of experience with the orthodox control, even after only a few minutes experience on the new control. The difference is greater for subjects with no previous experience of either. Non-operators compared with operators naturally perform less well when using the orthodox control, but it is interesting to note that their performance using the variable speed control is better than that of the operators using the orthodox control. It can be concluded that, for this laboratory task, a few minutes practice using the variable speed control provides more efficient performance than does many years of practice on the orthodox control. The precise numerical differences between performances are of no general interest since they are a function of the specific task.

The increased latency for stimuli away from the centre of the display is presumably due to the time required for eye movement. The mean point of fixation is apparently to the left of the centre, this could be due to the fact that although stimulus lights appeared at random, response lights always started from the left-hand side.

§ 5. Experiment IV. Comparison in the Factory of Two Methods of Speed Control

The performance of two highly skilled operatives was measured both before and after the replacement of an orthodox transmitter by the variable speed transmitter. Each subject was highly skilled and experienced on one of the common shoe production operations. To reduce the effect of novelty and the presence of observers, four different methods of measuring performance were used.

Factory records.—Since the operatives were on piecework it was possible to obtain details of their working hours and the total amount of work done in any period. From this information a mean time per shoe can be calculated.

Timer records.—Using a battery of electromagnetic counters energized by a synchronous motor and actuated by finger keys operated by the observer the time taken for each shoe can be obtained.

Setar records.—The Setar is an electronic digital time recorder which can be actuated by switches fixed to a sewing machine. In this way the time per shoe is obtained automatically.

Tachograph records.—A d.c. dynamo driven by the sewing machine is used to actuate a voltage pen-recorder, thus a complete trace of machine speed against time can be obtained.

The periods used were one month for Factory records, one week for Timer records, half a day for Setar records and half an hour for Tachograph records. Records were obtained immediately before and about six weeks after the introdnction of the variable speed transmitter.

5.1. *Vamping*

This operation involved stitching an orthodox Oxford vamp to the joined quarters with complete linings already attached to the quarters. A twin cylinder arm machine was used. The operative completed twin rows on a batch of shoes and then added a single row to each shoe by going through the batch again. The cycle time was taken as that between starting stitching on one shoe and starting stitching on the next. All cycles where something unusual happened, e.g. thread breakage, were excluded. The times per shoe obtained by the various recording methods are shown in Table 3.

Table 3. Vamping cycle times in seconds per shoe with standard and variable speed controls

	Approx. No. of shoes in sample	Standard	Variable Speed	Reduction
Factory records	4,500	101	102	—
Timer	1,000	62·3	52·1	16%
Setar	100	57·1	51·4	12%
Tachograph	20	55·9	46·8	16%

Table 4. Analysis of performance on vamping

Item	Standard	Variable speed
Number of stops per hour	572	444
Average length of a burst of stitching	1·6 sec	2·8 sec
Proportion of time during which machine is stitching	24%	28%
Cycle time for twin-needle row	41·9 sec	34·3 sec
Cycle time for single-needle row	20·4 sec	17·8 sec

From the Timer records changes in the pattern of starting and stopping can be demonstrated as shown in Table 4.

The results shown in these tables were confirmed by similar data from the Setar records. The different values obtained by the different timing techniques and the fact that the Factory records are almost identical, are expected effects which have been discussed elsewhere (Singleton and Simister, 1957).

5.2. *Undertrimming*

This consisted of sewing a row of stitching round the top of the shoe by which the lining was joined to the outsides and the excess lining was simultaneously trimmed off level with the outside.

A single-needle post-machine fitted with edge guide and trimming knife was used. Three of the same measures of performance were obtained and the results are shown in Tables 5 and 6.

Table 5. Cycle time in seconds per shoe for undertrimming children's Gibsons with standard and variable speed controls

	Approx. No. of shoes in sample	Standard	Variable speed	Reduction
Timer	800	15·8	14·0	12%
Setar	150	15·7	13·4	15%
Tachograph	40	12·5	11·9	5%

Table 6. Analysis of performance on undertrimming

	Standard	Variable speed
Number of stops per hour	636	500
Average length of a burst of stitching	1·91 sec	2·30 sec
Proportion of time during which machine is stitching	33%	32%
Cycle time for Gibsons	15·8 sec	14·0 sec
Cycle time for Oxfords	13·0 sec	12·1 sec

It was not possible to obtain accurate cycle times from factory records since the operative was engaged on a variety of work. Thus Table 5 refers only to Gibsons, while Table 6 (derived from Timer records) covers all the work done during the period of observation ; this was either Oxford or Gibson undertrimming.

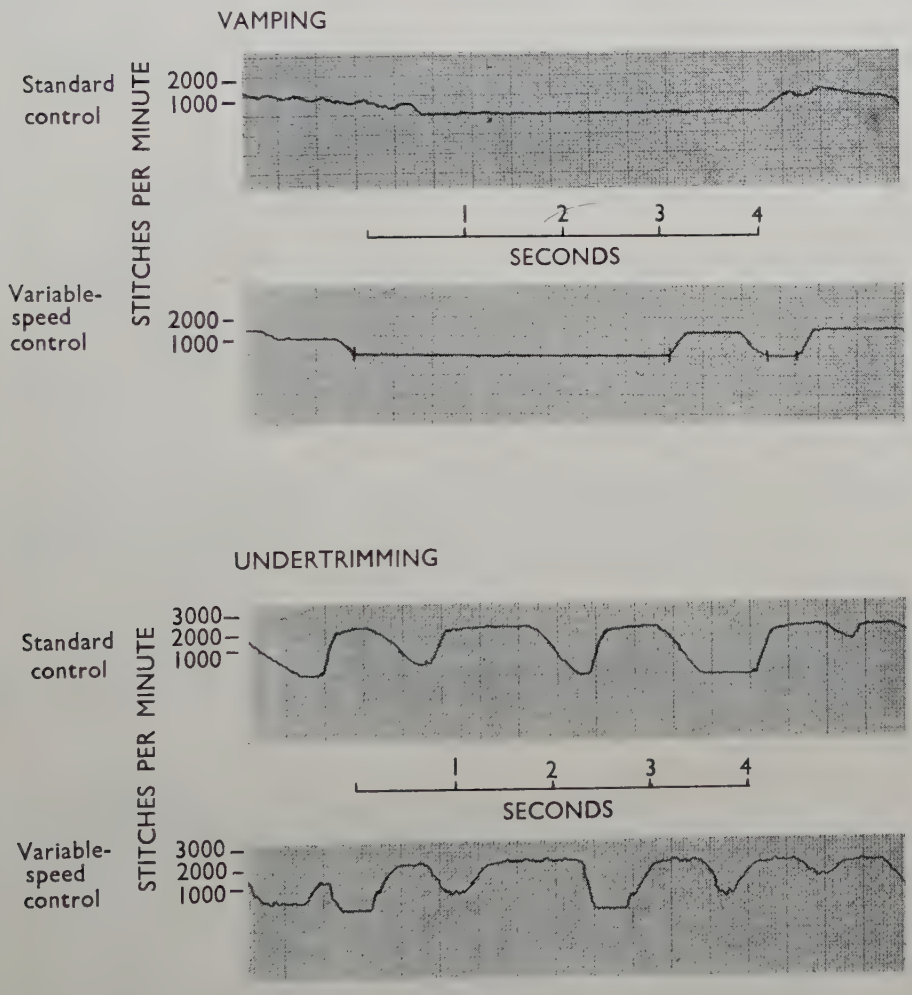

Figure 5.

It seems clear that, even for these experienced machinists, the new control resulted in faster and more efficient performance. There seems to be a potential improvement of speed of about 10–15 per cent. This is obtained by decreasing the number of stops and increasing the average length of a burst of stitching.

The way in which skilled machinists adapt to the limitations of the orthodox control is indicated by the traces in Fig. 5. The vamping machinist rarely requires the maximum stitching speed and she achieves intermediate speeds by moving the clutch plate just on and just off the flywheel so that the machine speed fluctuates about the mean speed required with a frequency of about 3 c/s. The undertrimming machinist uses a different technique. It will be remembered that she has an edge guide for the material so that for short periods she can stitch at maximum speed. She achieves slower speeds for curves by utilizing the accelerating and braking times of the machine so that she is oscillating the stitching speed through the whole range with a frequency of about 1 c/s. This oscillation, which is governed by the spacing of the curves, still appears in the trace obtained using the variable speed transmitter, but there are now phases where she does stitch at very low speeds and since this could only be done on the orthodox transmitter by stopping and starting again, the number of stops is reduced.

§ 6. Development Note

The results enumerated in this paper were obtained in 1956 and were used to interest transmitter manufacturers in the possibility of developing a commercial variable speed unit with a similar performance to that used in these experiments and with a low cost. Several firms began development work and in some cases this is not yet completed. One shoe firm obtained units with similar performance and validated them on production work using orthodox time study techniques ; they concluded that the saving on performance would be more than 10%. How this saving is translated into economic terms depends of course on its distribution between management and operatives. This is obviously a matter for the normal negotiating machinery but if, purely to obtain some sort of answer, it is assumed, entirely arbitrarily, that the saving is divided equally between the two, then earnings should increase by more than 5% and the capital cost of the units which have a life of at least 7 years would be recovered in about 3 years. These figures take no account of the savings on training time and on quality of work.

There are a number of points of interest here.

1. Ergonomics can very properly be used as a stimulus to engineering development and to specify the target performance and cost of the new machine.
2. It is often said that there is a gap of ten years between the conception of an idea and its utilization in production. This may seem excessive but it arises reasonably, as in this case, from say, two years on Ergonomics Research, four years on Engineering Development and a further four years before a commercially available machine is taken up on a reasonably wide scale by the user.
3. In this case, at least, the small scale validation by precise ergonomic techniques yielded the same results as that obtained later by larger scale time study evaluation.

All the numerical work and much of the testing of subjects was carried out by Miss P. Mobbs. The factory measurements were taken by R. Simister and R. Bednarz. Results shown in Fig. 2 were obtained by R. G. Coulson and the statistical analysis of the data in Fig. 4 was carried out by J. R. Manning. The early stages of this work were assisted by a grant from F.O.A. Conditional Aid Funds.

STATISTICAL APPENDIX

The apparent trend of the results illustrated in Fig. 4 was examined by the following method :-

Let x be the number of the target light, and let t be the corresponding reaction time. Then using orthogonal polynomials, we can fit a curve to the experimental results in the form :—

$$t = a_0 + a_1(x - 25/2) + a_2[(x - 25/2)^2 - 575/12] + \ldots .$$

For the mean reaction time of the twelve subjects the curve is :—

$$t = 0{\cdot}7798 + 0{\cdot}000646(x - 25/2) + 0{\cdot}002384[(x - 25/2)^2 - 575/12]$$

the coefficients a_1 and a_2 are both significantly greater than zero, but a cubic term does not improve the fit significantly. The curve represents a parabola with a minimum at $x = 11{\cdot}1$. In a similar way, parabolas can be fitted to the results of each of the twelve trials. In no case does a cubic term improve the fit significantly. An analysis to covariance of the twelve sets of results yields the following table.

	Sum of squares	d.f.	m.s.
Deviations about individual parabolas	5·1166	252	0·0203
Differences between quadratic coefficients a_2	0·3111	11	0·0283
Differences between linear coefficients a_1	0·2273	11	0·0207
Differences between means a_0	3·7846	11	0·3441

Hence there are no significant differences amongst the twelve quadratic coefficients a_2, and amongst the twelve linear coefficients a_1, that is, the twelve curves can be represented by twelve similar parabolas, all with their vertices on the line $x = 11{\cdot}1$.

In other words, each trial can be characterized by the mean reaction time.

Dans une série d'expériences on a étudié une nouvelle méthode de régulation de la vitesse sur les machines à coudre utilisées dans l'industrie de la chaussure. On a pris en considération le degré d'habileté requis dans la tâche. Le nouveau dispositif a été expérimenté simultanément en laboratoire et en usine. Il est discuté de l'opportunité de ce genre d'investigation.

Eine neue Methode der Geschwindigkeitsregelung für Nähmaschinen, die in einer Schuhfabrik gebraucht werden, wurde in einer Riehe von Versuchen beobachtet. Die Geschicklichkeits-Anforderungen für diese Arbeit wurden untersucht. Die neue Kontrollvorrichtung wurde im Laboratorium und in der Fabrik getestet. Die Berechtigung für diese Art von Untersuchung wird diskutiert.

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TEMPERAMENT, INSPECTION EFFICIENCY, AND TIME OF DAY

By W. P. Colquhoun

Medical Research Council Applied Psychology Research Unit, Cambridge

The efficiency with which subjects detected brief, rarely appearing signals in an inspection task was found to be related to their degree of ' unsociability ', as measured by a questionnaire. In tests conducted during the forenoon, good performance was associated with a high unsociability rating ; in afternoon tests the direction of the relationship was reversed. Further experiments are planned to determine the reasons for this change.

This note describes some observations on the relationship between temperament and performance which were made during an investigation of factors affecting efficiency at signal detection in a vigilance situation.

In a series of experiments, 102 young adult male subjects performed, for a single session of 40 or 60 min, a task which simulated a common type of industrial inspection operation. Apparatus previously described (Colquhoun 1959) was used to present a series of displays, each of which consisted of a row of six small green discs (Munsell classification : Hue 7·5 GY ; Chroma 2 ; Value 8). The subject was required to report the occasional and unpredictable appearances of a disc of greater brightness than the remainder (the difference in brightness was less than a single step on the Munsell Value scale). Several variables were considered during the investigation, in particular the following characteristics of the displays : overall frequency ; regularity in time of appearance ; duration of exposure ; and proportion containing a signal. Each subject was tested individually, under one of 10 combinations of the experimental conditions. Subjects were allotted to one of these combinations in groups of 6, each member of a group being tested at the same time of day, viz. 10 a.m., 12.30 p.m. or 3 p.m. Of the 10 combinations of conditions, one was investigated at all three test times, five at two of them, and four at one time only.

Bakan (1959) has shown that the efficiency with which an individual detects signals in a vigilance task is related to his score on Part II of the Heron personality inventory (Heron 1956). This part of the inventory gives an index of ' unsociability ', which is generally accepted to be closely associated with

Values of ' tau ' for 17 groups of subjects

	Combinations of Experimental Conditions									
	A	B	C	D	E	F	G	H	I	J
Time of test										
10 a.m.	+0·50	+0·69	0	+0·45	+0·55	+0·16	+0·41	+0·41	—	—
12.30 p.m.	−0·44	—	—	—	—	—	—	—	−0·33	—
3 p.m.	−0·50	−0·83	−0·50	0	+0·36	0	—	—	—	−0·36

introversion. Since the Heron inventory was given routinely to all subjects employed in the experiments it was possible to compare the Part II scores with the performance results for each group of subjects tested. A measure of the degree of rank correlation of the score on Part II of the inventory and inspection efficiency (measured as the proportion of signals detected during the session)

was obtained by computing the value of ' tau ' (Kendall 1948) in each case. The observed values are given in the table.

Although the average magnitude of the values of ' tau ' obtained justifies the conclusion that a degree of relationship between the inventory score and inspection efficiency does in fact exist, the results suggested that the sign of the correlation depends on the time of day at which the test session is held. At 10 a.m. relatively unsociable (introvert) subjects tend to be more efficient at the task. In the afternoon, on the other hand, the position is reversed. Both at 12.30 p.m. and at 3 p.m. subjects with a relatively unsociable temperament tend to do less well than their more sociable (extravert) colleagues.

Taking a chance probability (two-tailed test) of less than 0·05 as the criterion, the null hypothesis that the inventory score and inspection efficiency are unrelated for each of the eight combinations of experimental conditions investigated in the forenoon (tested by the ratio of the sum of all values of ' tau ' to its appropriate standard deviation) is rejected ($p = 0{\cdot}004$), i.e. at this time of day there is a statistically significant *positive* correlation between the two measures. The same hypothesis for each of the nine combinations investigated in the afternoon is also rejected ($p = 0{\cdot}02$), i.e. at this time of day there is a statistically significant *negative* correlation between the two measures. Considering only the six cases where a particular combination was investigated at both times, the hypothesis that the relationships are identical for forenoon and afternoon is rejected by a sign test ($p = 0{\cdot}03$).

It appears reasonably certain, from the above tests, that the relationship between the inventory score and efficiency at this task in the forenoon differs from the relationship in the afternoon. There are, clearly, several possible explanations of this phenomenon, but it is hoped that further experiments now being conducted by the author and his colleagues will enable distinctions to be made between the various factors that may be involved.

I am indebted to Dr. M. Stone for statistical advice, and to the Royal Navy for supplying the subjects.

On a trouvé que le'efficacité avec laquelle des sujets détectent des signaux brefs, qui apparaissent rarement, est relatif à leur degree ' d'insociabilité ', comme mesuré à l'aide d'un questionnaire. Dans les essais conduite pendant l'avant-midi, une bonne performance était associée avec un degré d'insociabilité élevé. Dans les essais de l'apres-midi, la direction de cette relation était renversée.

Des experiments additionelles sont considerées pour déterminer les raisons de cette change.

Der Leistungsgrad mit dem Vps. kurze, selten erscheinende Reize entdeckten wurde gemessen, und eine Korrelation mit ' unsociability '—durch Fragebogen bestimmt—wurde festgelegt. In den Versuchsreihen am Vormittag gute Leistung und ein hoher grad von ' unsociability " standen im Zusammenhang ; am Nachmittag war der Zusammenhand umgekehrt. Weitere Versuche um die Ursache dieses Wechsels zu erforschen sind geplant.

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REVIEW

Recent Innovations in Methodology for Training and Training Research. By A. F. Smode and K. W. Yarnold, March 1960. Prepared for Office of Naval Research by Dunlap and Associates Inc., Stamford, Connecticut.

It is increasingly difficult to maintain reasonably comprehensive contact with the great volume of American government sponsored research in Ergonomics which appears as reports from centres, such as W.A.D.C. and O.N.R. Much of this work is of considerable current interest and review reports of this kind are therefore important to research workers in related fields. The report will not be of practical interest to training officers in the services or in industry, since despite the dual objective in the title, almost all the work described is in the field of training research rather than training. Similarly the evaluation deals with the relative importance of specific projects to the advancement of knowledge rather than the progress of application. Nonetheless the authors appear to have read the literature and reported it accurately. There are about two hundred references of which more than half are dated 1955–60. Miniature surveys which the reviewer found informative were those dealing with team performance, teaching machines, space flight simulation, motor-skill scoring, information feedback and malfunction location (better known as trouble shooting). There are valuable lists of new pieces of apparatus for particular purposes. However, these are so formidable that one is left with the impression that, just as in the past the experimental psychologist has suffered from an over-enthusiastic use of statistics, he may now be falling victim to the indescriminate use of complex electronic engineering.

W. T. Singleton

CORRIGENDA.

The following corrections should be made to the paper "The measurement of sensory-motor performance : survey and reappraisal of twelve years' progress" by A. T. Welford in the July number of this volume :

p. 220, Figure 13. For $1/I$ read $1/I'$

p. 221, line 1. For $(X_1 - X_2)$ read $X_1/(X_1 - X_2)$

INTERNATIONAL ERGONOMICS ASSOCIATION

STOCKHOLM CONGRESS 20–23 AUGUST, 1961

THE theme of the Congress will be the *Adjustment of Work and Working Environment to Man*, and the programme is planned for specialists in the different fields of ergonomics. Opportunity will be given for the presentation of papers on any topic of ergonomic interest, although it is intended that attention should be specially devoted to the following subjects :

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Papers may be presented in English, French or German. All papers should include a summary in the language of the paper as well as in English if presented in French or German. Summaries should not exceed 200 words, and two copies, typed in double-spacing, are desirable. Original contributions will be given priority over reviews of previously published material.

The names, academic degrees, titles, and complete addresses of the author and of any co-authors must be included in each abstract. When there is more than one author, the author who is to present the paper should be listed first.

Abstracts should be sent to the Organizing Committee before 1 March, 1961, and full manuscripts before 1 July, 1961. Shortly after 1 March the Organizing Committee will inform each author if there will be time for his paper to be presented at the Congress.

The time allotted for each paper will be limited strictly to fifteen minutes including slides. Time for discussion will be limited to five minutes.

The Abstracts will be available for participants at the beginning of the Congress. The complete papers will be published later in the Proceedings of the Congress.

During the days following the Congress, visits to institutes and industries in Stockholm and in other parts of Sweden will be arranged for the participants.

Notification of intention to attend the Congress and any other correspondence should be sent to Professor Sven Forssman, Svenska Arbetsgivareforeningen, Postbox 16120, Stockholm 16, or Mr. Torsten Olson, GCI, Lidingövägen 1, Stockholm Ö, Sweden.

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